Thematic report on urban energy planning

buildings, industry, transport and energy generation

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Publication date:
2015

Document version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Meijers, E., Romein, A., Stead, D., Groth, N. B., Fertner, C., & Große, J. (2015). *Thematic report on urban energy planning: buildings, industry, transport and energy generation*. EU-FP7 project PLEEC. PLEEC Report Vol. 4.3 http://www.pleecproject.eu/results/documents/viewdownload/131-work-package-4/561-d4-3-thematic-report-on-urban-energy-planning-buildings-industry-transport-and-energy-generation.html

PLEEC
PLANNING FOR ENERGY EFFICIENT CITIES

Deliverable 4.3

Thematic report on urban energy planning: Buildings, industry, transport and energy generation

26 June 2015

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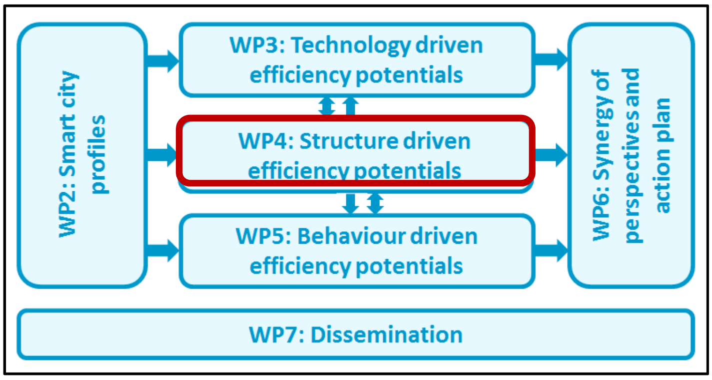
Abstract

Main aim of report

Deliverable 4.3 is the thematic report, studying key aspects of energy efficiency in spatial structures and urban planning. The thematic report summarizes the case study reports and supply condensed information by the key aspects regarding spatial structures and planning. The final deliverable of WP4, D4.4, will synthesize the findings on structure driven energy efficiency potentials and barriers in cities and feed into WP6.



WP4 location in PLEEC project

Target group

The main addressee is the WP4-team (cities and universities) but also WP6 and other partners in PLEEC working with the final project results as e.g. the general model for an Energy-Smart City (D6.1). The report can also be used as a more general reference for the interested public, especially planning practitioners and researchers.

Main findings/conclusions

The report reviews relations between urban structure (spatial structure + institutional structure) and four core themes of urban energy:

- Urban planning and **energy use in buildings** (mainly residential buildings)
- **Industrial energy use** and urban form
- Spatial Planning, Urban Form and **Transport Energy Consumption**
- **Urban energy generation**

The reports ends with a summary of potential measure and policies of spatial planning in each of the four themes. However, we highlight also that it is crucial to consider the wider perspective and include considerations of potential rebound effects on direct and indirect energy use.

Activities carried out including methodology used

The report is based on material previously elaborated in WP4, including the 6 case reports (D4.2), as well as on general scientific literature of the field. The 4 main chapters of the report were written by different lead authors, while having, a close contact between the author team and a regular exchange of findings.The first full draft was up for discussion with the city partners at the project meeting in Santiago (Feb 2015). Following that, comments from several partners where incorporated in the final text.

The PLEEC project

Energy efficiency is high on the European agenda. One of the goals of the European Union's 20-20-20 plan is to improve energy efficiency by 20% in 2020. However, holistic knowledge about energy efficiency potentials in cities is far from complete. Currently, a

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variety of individual strategies and approaches by different stakeholders tackling separate key aspects hinders strategic energy efficiency planning.

For this reason, the PLEEC project – "Planning for Energy Efficient Cities" – funded by the EU Seventh Framework Programme uses an integrative approach to achieve the sustainable, energy–efficient, smart city. By coordinating strategies and combining best practices, PLEEC will develop a general model for energy efficiency and sustainable city planning. By connecting scientific excellence and innovative enterprises in the energy sector with ambitious and well-organized cities, the project aims to reduce energy use in Europe in the near future and will therefore be an important tool contributing to the EU's 20-20-20 targets.

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Table of Content

1 Introduction

The way we plan and build our cities is influencing the present and future demand for energy. The aim of this thematic report (Deliverable 4.3) is to explain how urban planning affects energy consumption and enables energy generation. Ultimately, this leads to a listing of planning-related strategies that cities can implement. In Deliverable 4.4 we will assess which strategies fit best with each PLEEC partner city, or, in other words, yields the highest energy efficiency gains. While we pay attention to what the PLEEC partner cities are already doing in terms of urban planning, the majority of this report is devoted to synthesising the scholarly knowledge that is available, but perhaps less well opened up to policy makers. We will particularly focus on how this knowledge translates into concrete planning strategies and when available, illustrate this with examples from policy practice in cities all over the world.

This thematic report contains 4 synthesising chapters. First we make a major division in the consumption and production of energy. The first three cover the relationship between urban planning and energy consumption. We split consumption into the three domains, or main uses of consumption, as generally found in the literature: energy use in buildings (chapter 2), in industry (chapter 3) and in transport (section 4). Energy consumption in buildings can be subdivided in residential and tertiary (offices, health sector, education, hotels and restaurants, wholesale and retail trade and other types of buildings) energy consumption. Chapter 5 then discusses how urban planning influences potentials for energy production. Finally, in chapter 6 we summarize potential panning strategies cities can adopt to decrease energy consumption and expand opportunities for local energy generation.

Table 1.1. Structure of the report

Chapter	**Structural dimensions in PLEEC**	
	Spatial structure (regional and local urban form, flows and functions)	**Planning/Institutional Structure**
Residential energy consumption	Chapter 2	
Industrial energy consumption	Chapter 3	
Energy consumption in transport	Chapter 4	
Urban energy generation	Chapter 5	

Out of the three main domains of energy consumption, the consumption in buildings (residential and services) accounts for the largest share in the EU. Generally, over a third of total energy consumption is in buildings. Buildings consume more energy than transportation or industry (see Figure 1.1), but the exact share differs somewhat between countries and cities, e.g. when there are energy-intensive industries located in a specific region (see e.g. section 3.2 on Eskilstuna). Transport accounts for about one-third of total energy consumption in the EU27, and industry for about one quarter.

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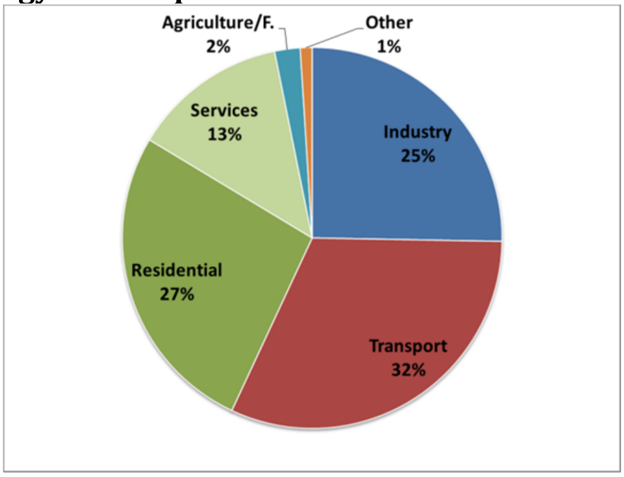
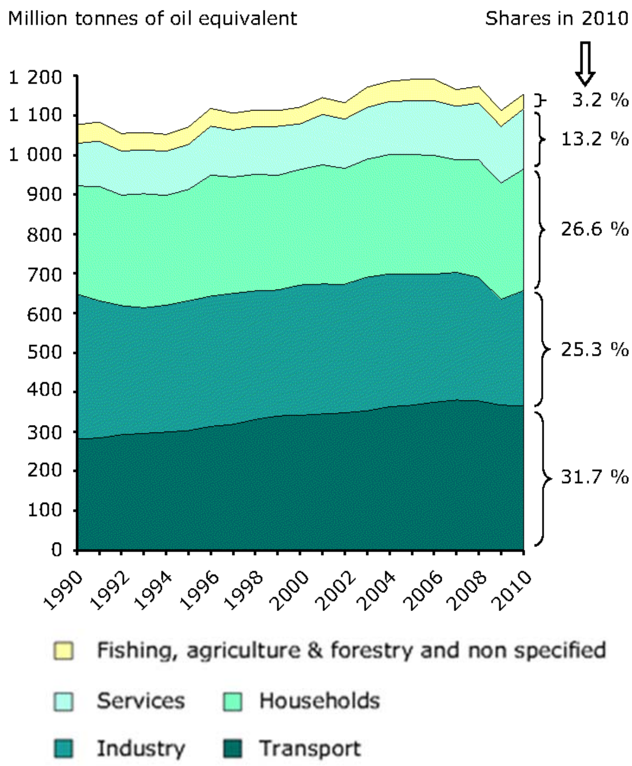
Figure 1.1. Final energy consumption breakdown into sectors in the EU-27, 2012.



Source data: European Union, 2012.

When one considers the development over time (Figure 1.2), we see that the share of industry has decreased somewhat over the years, while the shares of transport and services did increase. Total energy consumption in 2010 was slightly higher than in 1990.

Figure 1.2. Trends in total final energy consumption



Source: European Environment Agency (EEA).

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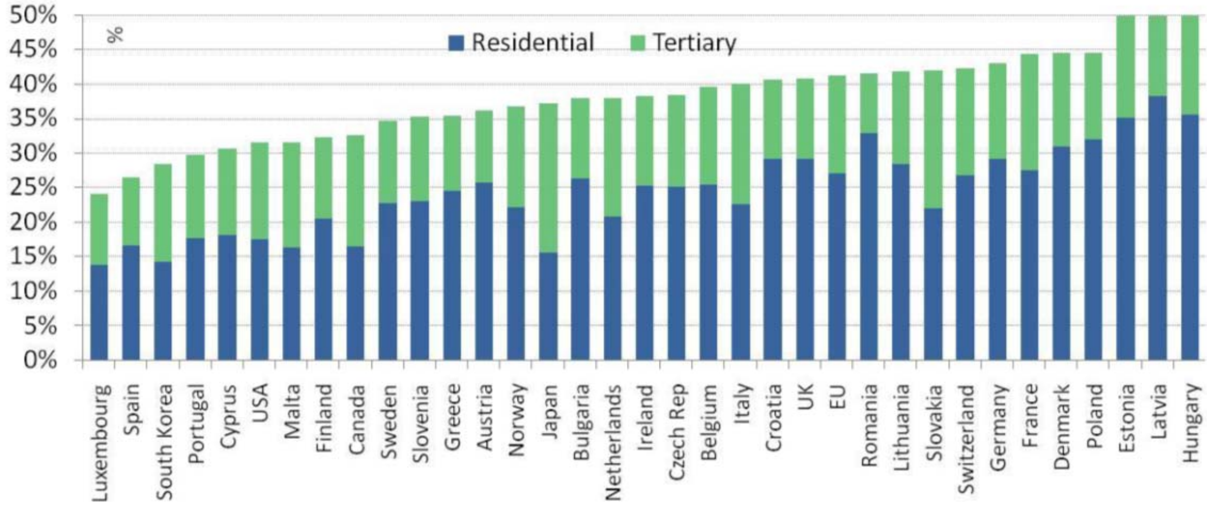
2 Urban planning and energy use in buildings (Evert Meijers)

2.1 Introduction

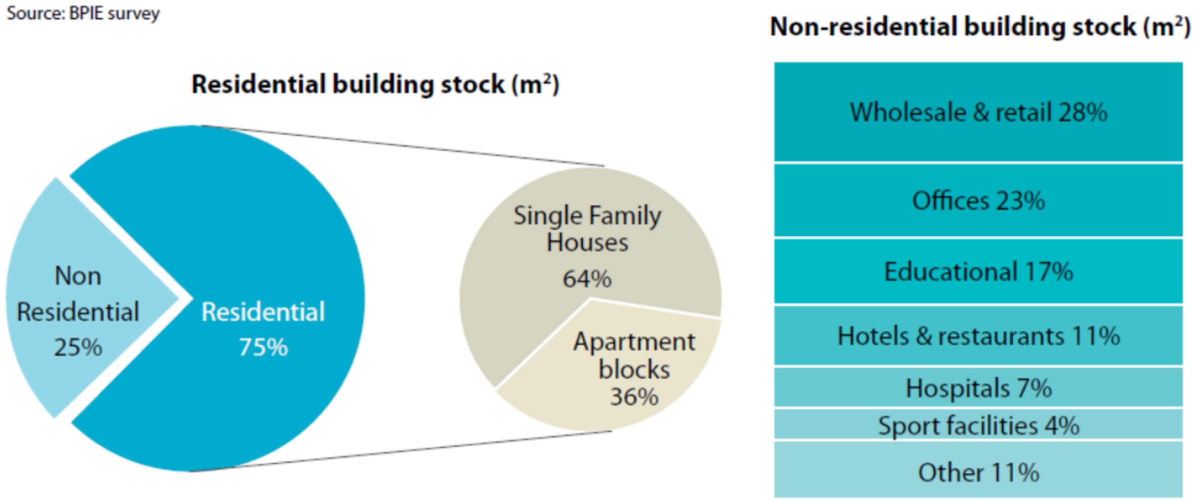
Generally, over a third of total energy consumption is in buildings. As we saw in the introduction, buildings consume more energy than transportation or industry, but the exact share differs somewhat between countries (Figure 2.1). Energy consumption in buildings can be subdivided in residential and tertiary (offices, health sector, education, hotels and restaurants, wholesale and retail trade and other types of buildings) energy consumption. The latter is also referred to as energy use in 'services'. About 25% of the buildings in Europe are in this services sector, 75% is residential. A breakdown in types of buildings is presented in Figure 2.2. The energy consumption in homes and in service sector buildings is not equal: annual unit consumption per m^2 for residential is 200 kWh/m^2, while non-residential amounts to 300 kWh/m^2.

Figure 2.1. Share of energy consumption for buildings in final consumption (2009).



Source: ODYSSEE-MURE project coordinated by ADEME, 2012. Source data: Eurostat.

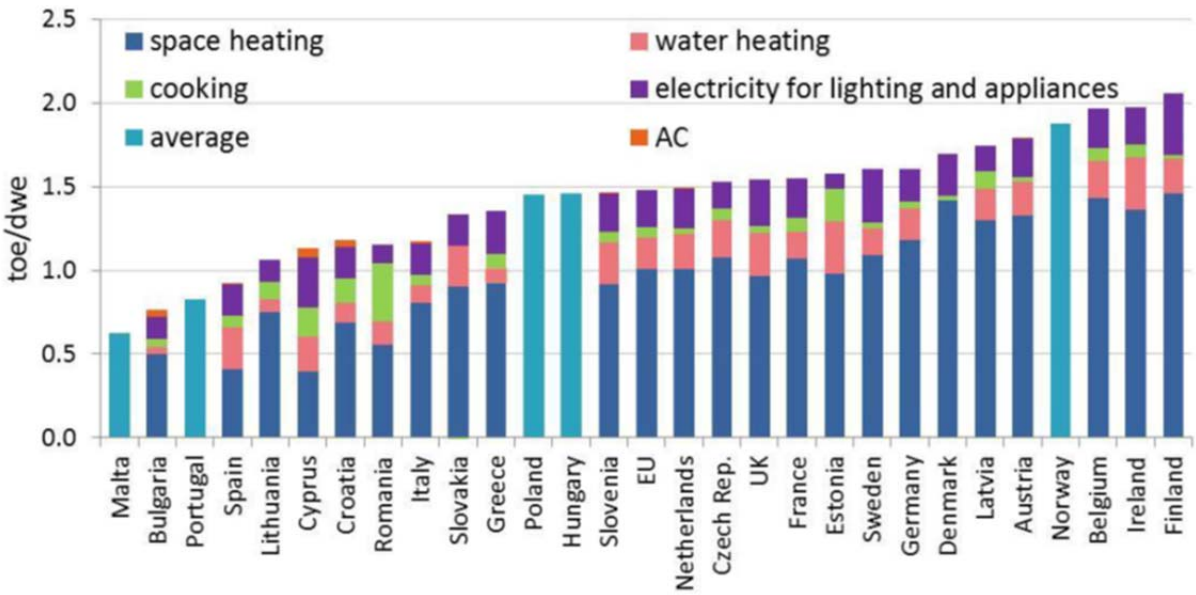
Figure 2.2. Break-down of building types in Europe.



source: Buildings Performance Institute Europe (BPIE) (2011).

Residential energy use is simply the consumption of energy in the home. The main types of residential energy-use are space-heating and space-cooling (e.g. air conditioning), accounting for over half of residential energy use, but other uses include water heating, lightning, electronics, refrigeration, cooking, washing/drying etc. Figure 2.3 presents the exact breakdown for European countries. What can be seen is that space heating very often accounts for even 70-80% of residential energy consumption in many European countries, with Spain, Romania and Cyprus being important exceptions. Only 8 countries publish data on cooling, but in those, it is a rather marginal phenomenon, certainly compared to for instance the United States. However, cooling appliances are becoming more widespread, particularly in Mediterranean countries, and also more efficient.

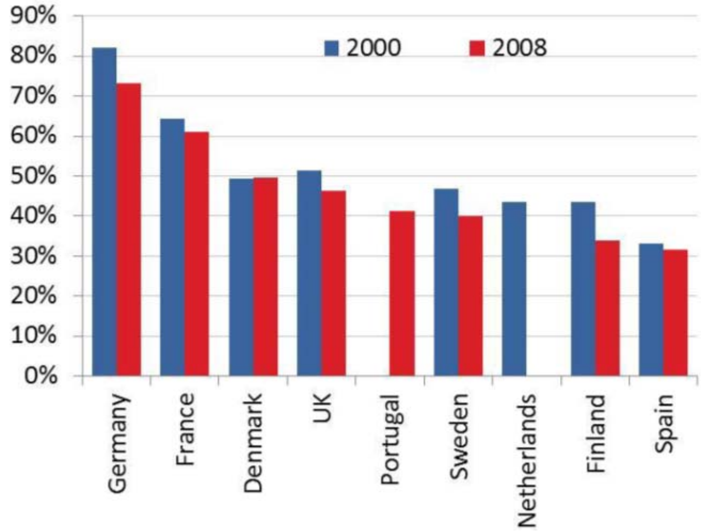
Figure 2.3. Residential energy consumption breakdown for European countries (average per household) (2009).



Source: Enerdata, Odyssee-database.

Space heating is also the main purpose of energy use in the services sector, see Figure 2.4. It amounts to over 70% in a country like Germany, but the share is somewhat lower in the PLEEC partner cities' countries. Also notable is the decrease of this share over time. According to Enerdata (2012), this can be attributed to technical energy efficiency improvements (insulation of buildings, efficiency of boilers, etc.) and because of the growth of other end-uses of electricity, such as in appliances.

Figure 2.4. Share of space heating in service sector consumption.



Source: Enerdata, Odyssee-database.

Obviously, the role of urban planning is limited when it comes to lowering energy consumption for residential and tertiary uses such as lightning, refrigeration or using electronic appliances. Here behavioural changes (e.g. turning of the light more often), technological changes (e.g. more energy efficient appliances) and policy incentives (e.g. to buy these energy efficient appliances) matter (and these are studied in the other WPs of PLEEC). For sure, attention in research and policy for building energy consumption has so far mainly been on technological and behavioural changes. This also holds for the policies of the PLEEC partner cities.

However, regarding the main uses of building energy consumption – heating and to a lesser extent cooling – urban planning makes a difference. Estimating the total possible impact of planning and urban form on residential energy consumption is difficult given the interaction between planning-behaviour-technology, in particular the technology used for indoor heating and cooling, but a conservative guess is that it is in the range of 10 percent of total building energy use (Ratti et al., 2005). Of course, that is an average, and it can be much higher especially in climates that require substantial heating or cooling during the year, not to mention in (land) climates that demand both. As we will see, particular measures can have very profound impacts on residential energy consumption, making that the potential scope of urban planning is larger, while in addition it has well-known effects on transport energy use.

The impact of urban planning on residential (or office) heating and cooling is through urban form that in turn affects the urban microclimate. The types of houses we build, their size, their orientation and the configuration of houses together in blocks, the street layout and the presence of open spaces as well as their vegetation all affect this microclimate, see Figure 2.5. However, the potential role of participatory ways of planning to increase awareness and empower local initiatives, also in the themes of energy efficien-

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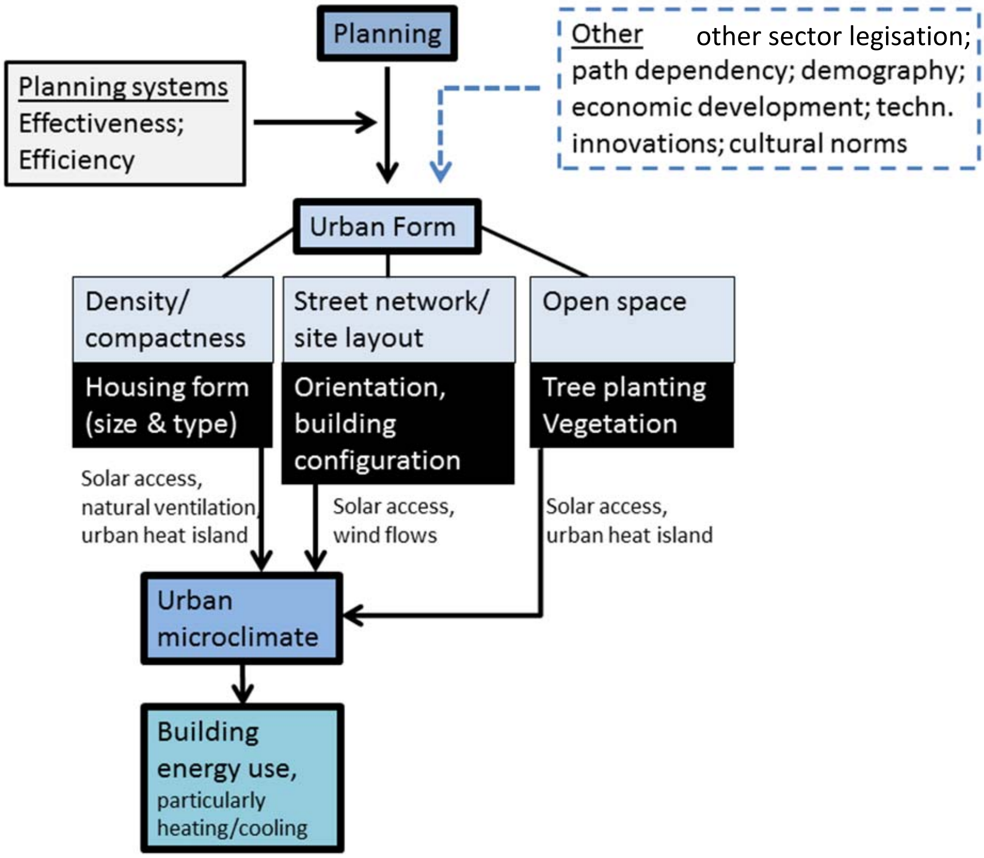
cy, should not be forgotten. Also, further system effects should be kept in mind, as e.g. compact building structure allow system efficiencies in e.g. district heating (see also chapters 4 and 5).

Figure 2.5. Urban planning and building energy use: causal pathways.



Source: Adapted from Ko (2013).

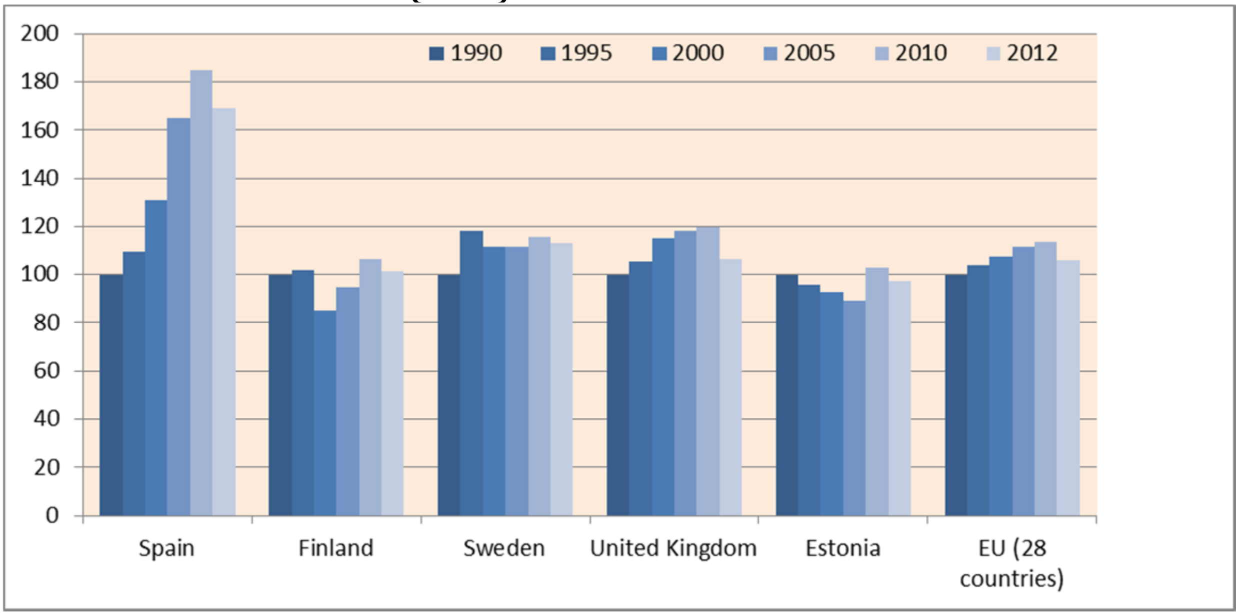
In this chapter, we will further explore the relationships between urban planning and building energy use as they have been identified in the scholarly literature (section 2.3). We illustrate our story with several examples from cities all over the world and how they use planning to reduce residential and services energy consumption. In section 2.4 we summarize potential strategies. However, first, we explore several trends regarding energy use in buildings.

2.2 Trends in energy use in buildings

Residential energy consumption

Between 1990 and 2012 total residential energy consumption in the EU28 increased by 23.8%. However, if we compare 2012 with 2000, the increase was just 1.9%. In 2007, residential energy consumption in the EU28 peaked, but since then, it has decreased by 8.1%. About one third of the decline in energy use can be explained by the financial and economic crises (Enerdata, 2012). Patterns for individual countries differ, however (see Figure 2.6). Several European countries, including Estonia, managed to decrease their residential energy consumption to a level even below the 1990 consumption. In most recent years almost all European countries saw their residential energy consumption decline. In PLEEC partner city countries the pattern varies. While Sweden has a rather stable level of residential energy consumption the last 15 years, Spain witnessed a rapid increase up to 2010. On a somewhat smaller scale, this also holds for Finland and the UK. The UK saw a substantial decline in the most recent years.

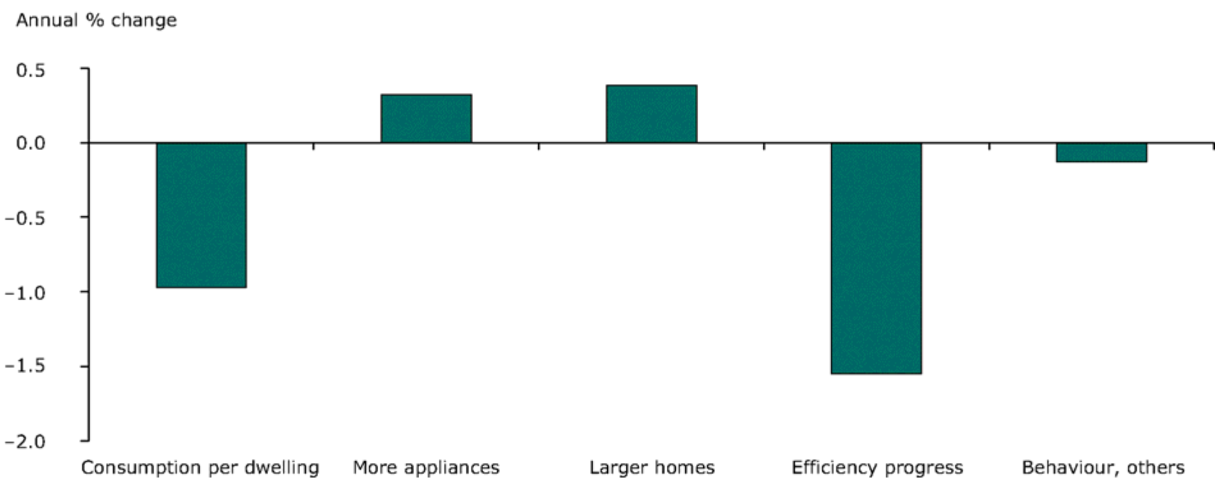
Figure 2.6. Development residential energy consumption levels in PLEEC partner cities' countries since 1990 (=100).



Source data: Eurostat.

The question is why residential energy consumption first increased and later decreased. As can be seen in Figure 2.7, this results reflects a balance between several drivers of energy change. What can be seen is that the gains of technological and behavioural advances are compensated to some extent by an increase in average dwelling size and an increasing number of appliances (more electrical appliances).

Figure 2.7. Drivers of the change in average annual energy consumption per household in the EU-27 between 1990 and 2010.



Source: European Environment Agency (EEA).

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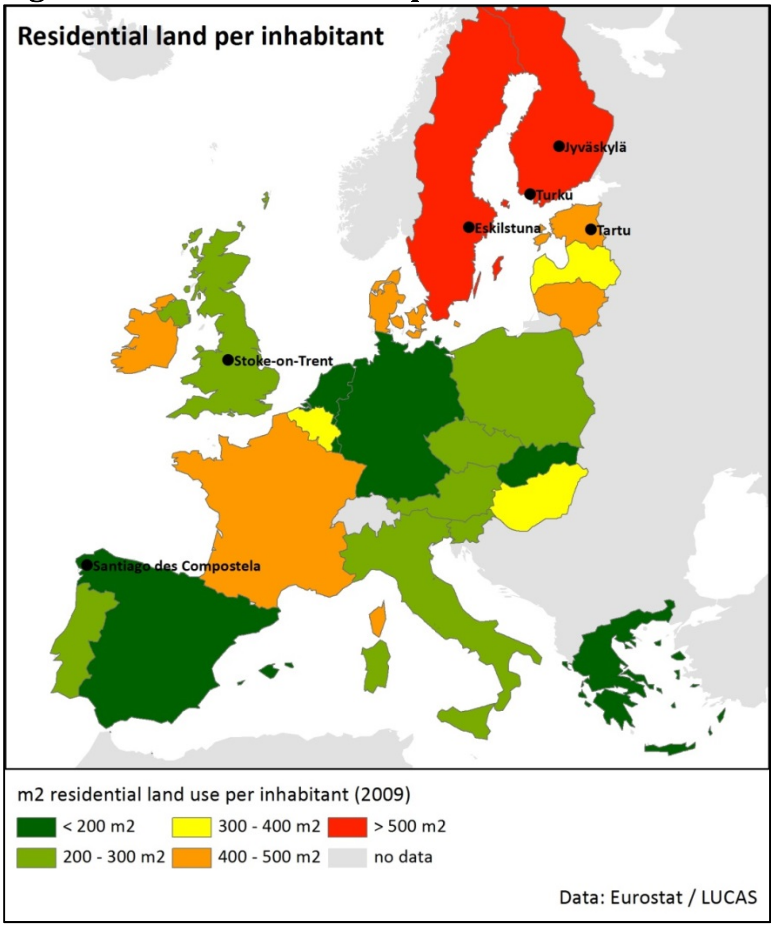
The trend towards larger homes that require more energy for in particular space heating is strongly related to mobile, usually car-based lifestyles, driving the conversion of former agricultural or unbuilt land. Higher availability of land permits lower ground prices and hence larger homes. There are striking differences between the PLEEC partner cities in terms of the available residential land per inhabitant (see Figure 2.8), leading to much higher densities in some of the countries (see Table 2.1), which is also reflected in a higher share of detached housing (Table 2.2).

Figure 2.8. Residential land per inhabitant.



Source: Own elaboration based on Eurostat

Table 2.1. Different densities in PLEEC partner cities

Inh. per km^2	Eskilstuna	Jyväskylä	Santiago	Stoke	Tartu	Turku
admin. area	91	115	437	2695	2522	736
settled area	1945	1394	6552	3166	3396	2403

Source: PLEEC WP2 report 'Energy Efficiency Indicators – Empirical results across key fields and cities'.

Table 2.2. Share of detached houses in PLEEC partner cities.

	Eskilstuna	Jyväskylä	Santiago	Stoke	Tartu	Turku
Share of detached houses	53 %	83 %	63 %	15 %	75 %	71 %

Source: PLEEC WP2 report 'Energy Efficiency Indicators – Empirical results across key fields and cities'.

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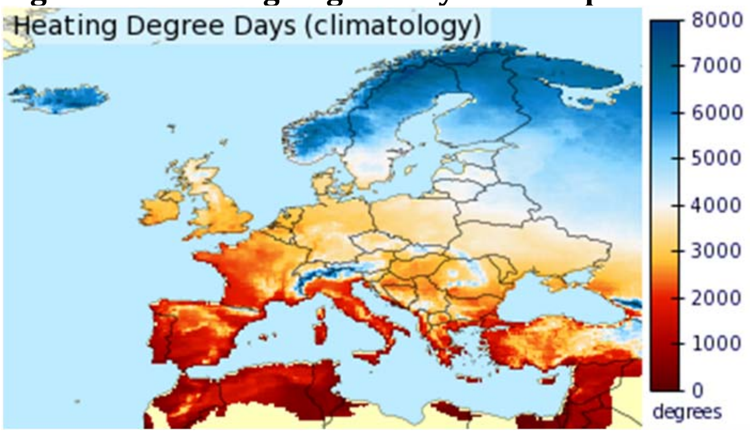
The general energy consumption levels are obviously influenced by economic and demographic developments, as well as changing weather conditions. For instance, the number of days on which heating is needed varies per year and per country. This is measured in so-called 'Heating Degree Days' (HDDs), which is a proxy for the energy demand needed to heat a home or a business; it is derived from measurements of outside air temperature. It is defined as the sum of the differences between the observed daily mean temperature and 17˚C for days where the average temperature drops below 17˚C (and heating is required). Figure 2.9 presents the long-term average HDDs in Europe.

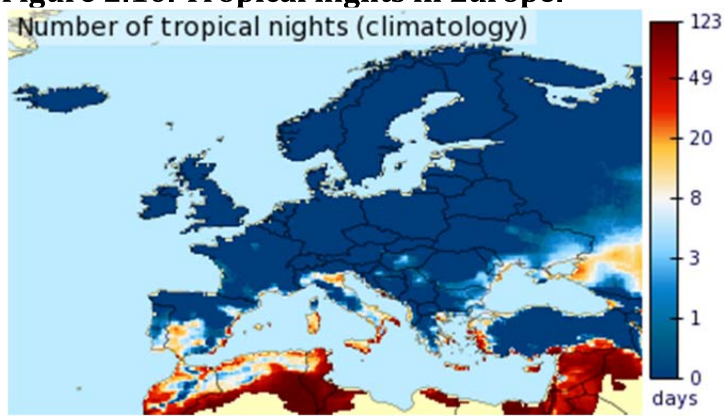
Figure 2.9. Heating Degree Days in Europe.



Source: EURO4M Climate Indicator Bulletin.

The counterpart of HDDs are Cooling Degree Days (CDDs), the days on which cooling is required. No recent maps could be found, but an equally good measure is the number of tropical nights (when minimum temperatures do not drop below 20˚C), which is perhaps an even better proxy for the need to use cooling – see Figure 2.10.

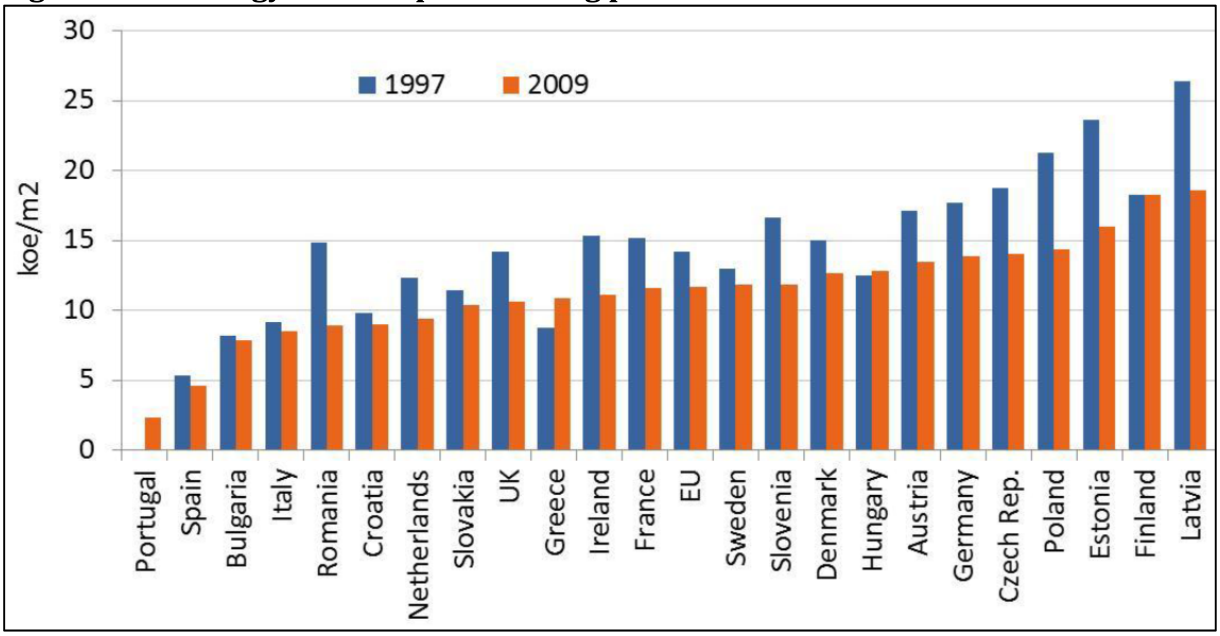
Figure 2.10. Tropical nights in Europe.



Source: EURO4M Climate Indicator Bulletin.

Residential energy use per capita and per building are two other indicators that illustrate residential energy efficiency across Europe well. However, buildings vary in size. One way to solve this is by considering energy use per m^2, see Figure 2.11 that concerns just space heating. Interesting to see is that in many countries the energy consumption for heating is decreasing, except for Greece, Hungary and Finland.

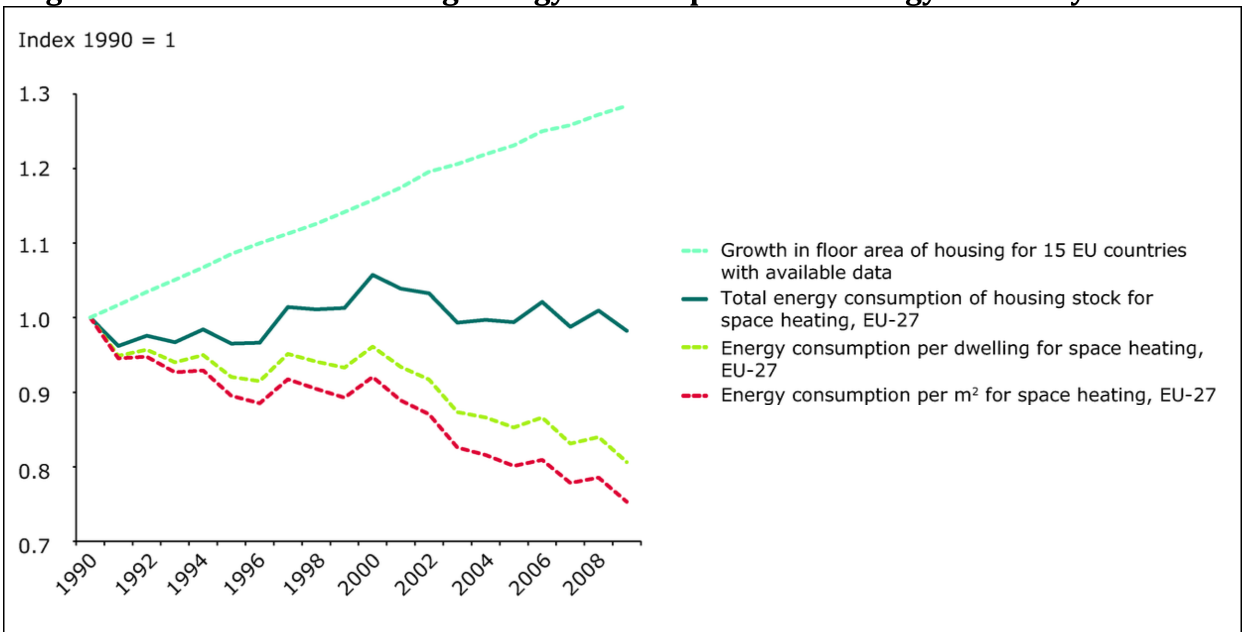
Figure 2.11. Energy use for space heating per m², 1997 and 2009



Source: Enerdata, Odyssee-database.

However, there is a rebound effect. The decrease in energy consumption per m² presented in Figure 11 is offset to quite a substantial extent by the increase in volume of houses. In just 20 years the surface of houses grew by almost 30%. As Figure 2.12 shows, the consumption per dwelling for space heating decreased less than the consumption per m². The total energy consumption of houses remained fairly constant over time.

Figure 2.12. Trends in heating energy consumption and energy efficiency.

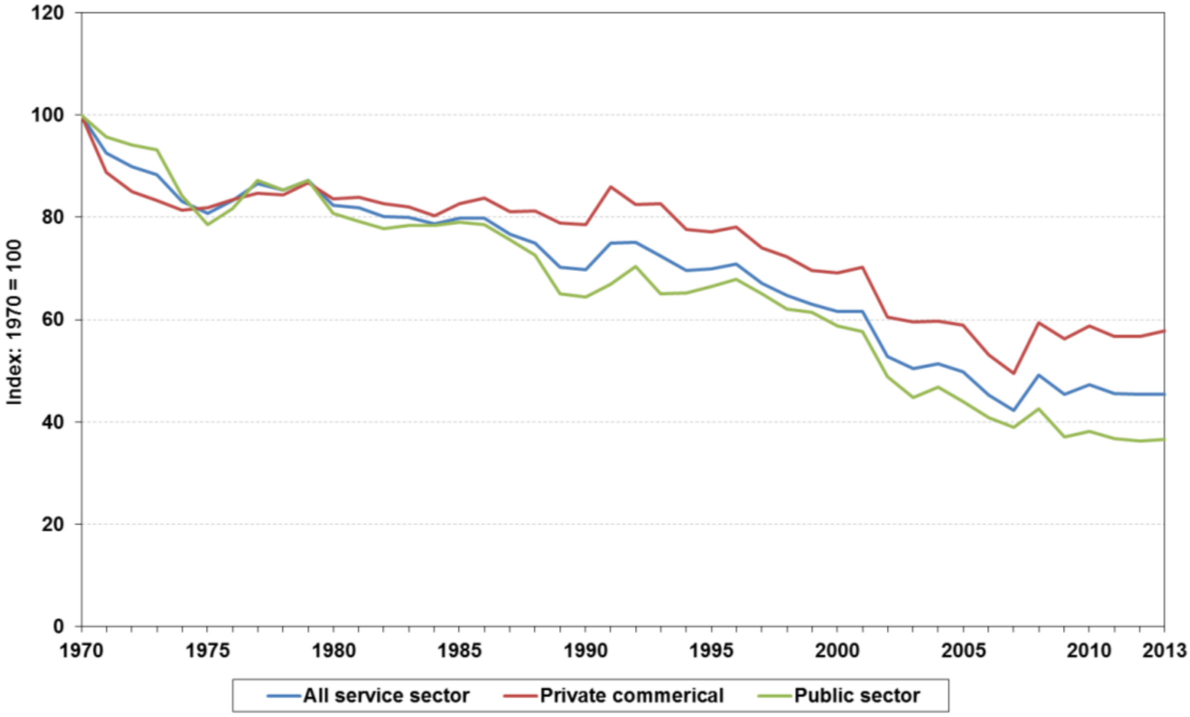


Source: European Environment Agency (EEA).

Services sector buildings

Much of the trends mentioned for the residential energy consumption also hold for the services sector. For instance construction techniques and building regulations on isolation levels are largely similar. Here, however, it makes sense to relate the energy consumption to the output generated by this growing economic sector. For instance, in the UK, total energy consumption in the service sector has increased in the past decades. However, taken into account that the output of the services sector also increased substantially, the 'intensity' or energy efficiency did increase. Energy consumption per unit of output fell by 55 per cent between 1970 and 2013 in the service sector as a whole. Energy efficiency improved at a faster rate in the public sector (63%) compared to the private commercial sector (42%) – see Figure 2.13. Remarkable is the stability of energy efficiency in more recent years.

Figure 2.13. Energy intensities for the whole service sector, private commercial and public sectors, UK (1970 to 2013)



Source: Department of Energy & Climate Change, 2014.

Compared to the residential sector, the services sector is more complex and heterogeneous. It includes for instance offices, retail, hospitals, hotels, restaurants, schools, sports and leisure centres. Sometimes, these functions can be found in the same building. This makes it harder to understand energy use, since end-uses such as lighting, ventilation, heating, cooling, refrigeration, IT equipment and appliances vary greatly from one building type to another. For instance, hospitals or hotels and restaurants consume up to double as much energy per m^2 than offices, schools or retail functions (BPIE, 2011).

2.3 Urban form and the urban microclimate

Local building traditions have always incorporated climatic and energy considerations in the design of buildings, the street layout and the urban form of cities. These traditions have become somewhat 'lost' due to industrialisation (and hence upscaling) of building construction since the 19th century, the imposition of general building norms for large administrative entities and more recently globalisation, leading to a perhaps more uniform style of building and urban development that pays little tribute to the often rich local knowledge on energy efficient building. There is a reason that cities in warm climates often have light-coloured buildings, narrow alleyways and compact urban designs: this serves to keep the heat out of the city. Likewise, in northern climates, strategies to capture winter solar heat have a long history. Here we further explore the scheme presented already in the first paragraph of this section to synthesise findings from the literature on the relationship between urban form and microclimate.

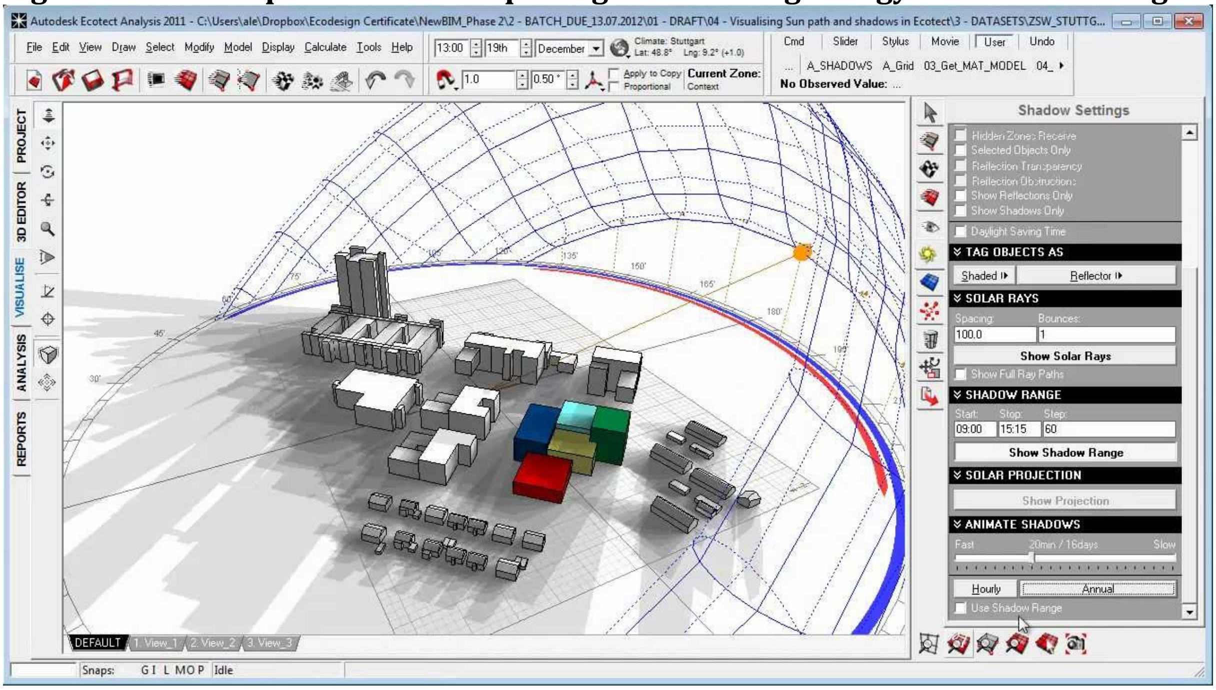
Density/compactness

Increased density is by many proposed as a strategy to enhance the use of public transit and more sustainable ways of transportation such as walking and cycling. Its effect on residential energy efficiency is more ambiguous. Population density in cities is correlated with housing size and type. In principle, multi-family dwellings (apartment blocks, flats), allowing for greater densities, tend to be more energy efficient than single-family, detached dwellings, also when measured in terms of per household or per capita energy consumption. The average household in all types of single-family housing uses roughly twice as much energy as the average household in a multi-family dwelling (Ko, 2013). Partly, this is simply because single-family detached homes tend to be larger, and hence, require more energy for heating and cooling given the larger volume. For instance, Ewing and Rong (2008) show that an otherwise identical household in a multi-family dwelling consumes 54% less heating energy and 26% less cooling energy. These are substantial differences. There are, however, indications that energy consumption differences between different, but more recently built housing types are decreasing (see e.g. Holden and Norland's 2005 study on Oslo) as a consequence of new building regulations. Density only indirectly influences residential energy consumption, it's effect being mediated by factors such as housing type and size, which in turn are related to socio-economic demographics such as household income and ownership (Ko, 2013).

Related to density is the concept of compactness – which basically states how tightly spaced houses, offices, stores etc. are within the city boundaries and in which mix and location they should occur. The concept also covers street widths, the distances between buildings and their height. The aspect ratio concerns the ratio of building height to street width. Its influence on residential energy consumption depends on the climate. In hot and dry climates, wide streets, and hence more solar access, may exacerbate the urban heat island effect and this effect often offsets the benefits of natural ventilation of wide streets. Narrow, winding streets would be more preferable. However, in colder climates, wide streets and lower building heights are essential for solar access, especially in winter. More compact urban forms may block solar access and increase residential energy consumption (Steemers, 2003). Compactness may also negatively influence opportunities for generating solar energy as shading may be a prominent issue if not well planned for.

Various statistical packages have been developed to explore solar access, sunlight hours, shadow ranges etc. An example is Ecotect (Figure 2.14). These issues have also been translated into planning guidelines, e.g. by the city of Boulder, CO (close to Denver) – see box.

Figure 2.14. Example of statistical package stimulating energy efficient building.



Source: Autodesk.

Solar access guide – City of Boulder.
In response to the diminishing supply and increasing cost of conventional energy resources, the City of Boulder enacted an ordinance to protect the use of solar energy. The ordinance guarantees access to sunlight for homeowners and renters in the city. This is done by setting limits on the amount of permitted shading by new construction and requiring that new buildings be sited to provide good solar access. The ordinance is designed to protect access for a four hour period on December 21st. The ordinance also sets standards for the siting of new development. It requires that all units in new developments which will not incorporate solar features include to the maximum extent possible:
1. long axis within 30 degrees of east-west;
2. roofs which are physically and structurally capable of supporting at least 75 square feet of solar collectors per dwelling unit;
3. unimpeded solar access through the provisions of this ordinance or through private covenants.

Planners are available for advice and help.
Source: City of Boulder.

Street network/site layout

Positioning a building well on its site is critical to ensure it receives sufficient sunlight. In particular in northern lattitudes, orienting a building within 10^0 to 30^0 of true south maximises solar access (Littlefair et al., 2000). The effects of building orientation should not be underestimated. For instance in London, changing building orientation from true south to true west leads to 9-16% more energy used for space heating (Steemers, 2003), whereas Randolph and Masters (2008) found that heating demand decreased by 20% for a house that is oriented to the south (having an east-west roof peak) compared to one that is oriented to the west or east. This can lead to substantial lower energy bills, see Figure 2.15.

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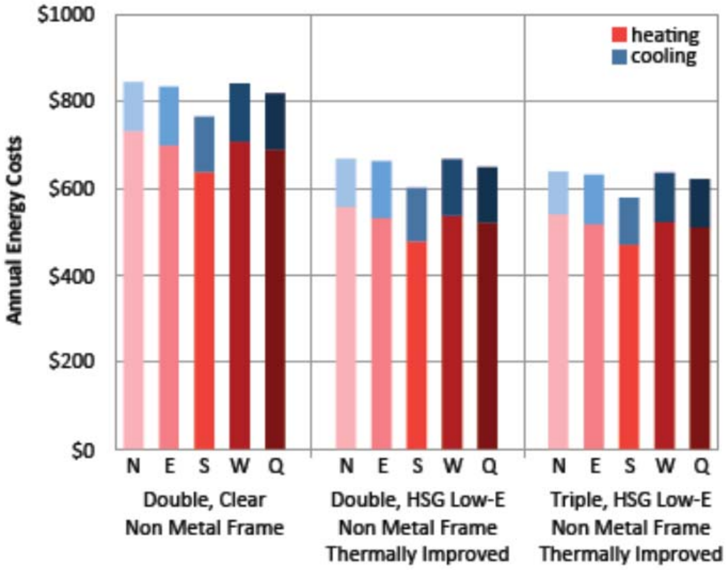
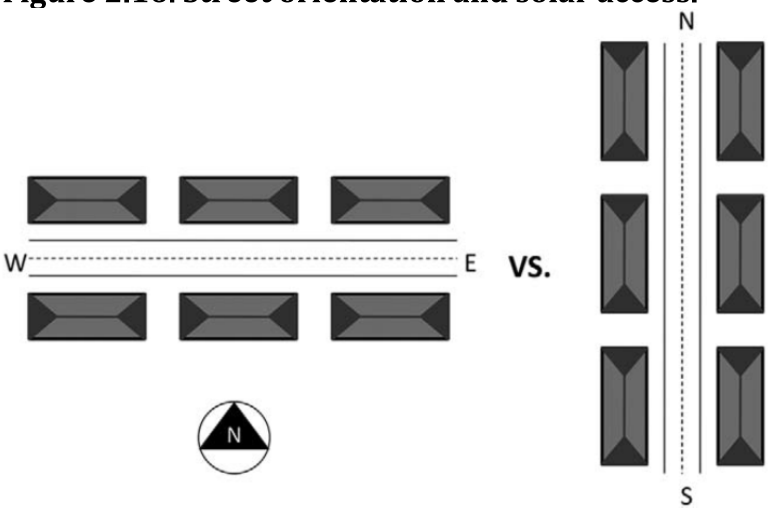
Figure 2.15. Impact of window orientation on annual energy costs in Minneapolis for different type of windows.



Source: Regents of the University of Minnesota, Center for Sustainable Building Research, 2013.

Building orientation is generally linked to street orientation, as it is rare to position a building independent of its property boundaries to maximise solar access. Generally, an east-west orientation of streets allows for north–south lots and hence, accommodates more south-facing buildings, see Figure 2.16. Again, this is not desirable in hot climates, where north-south street orientation is preferable to avoid the need for cooling in summer.

Figure 2.16. Street orientation and solar access.

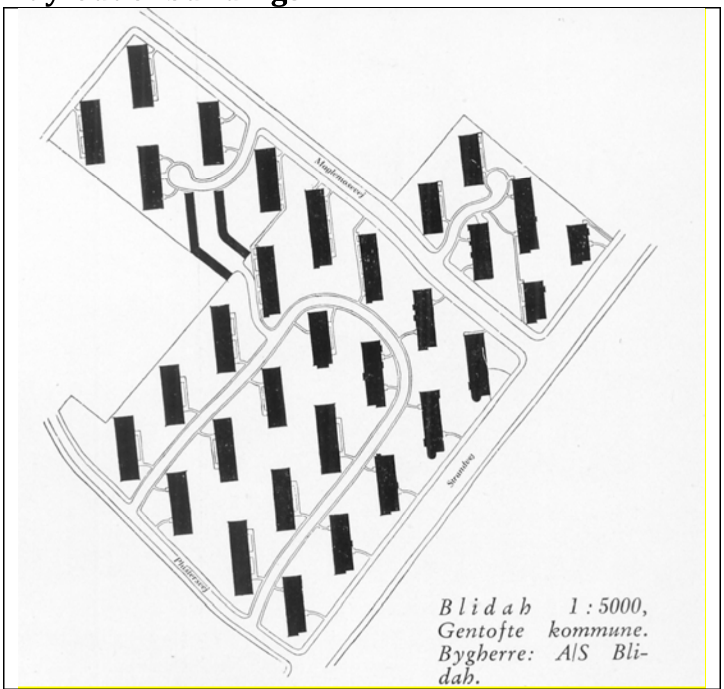


Source: Ko, 2013, after Randolph and Masters, 2008.

Street orientation is also important because it influences the possibilities for wind ventilation in warm periods and the protection from cold winds. Wind velocities at street level can be suppressed or increased through urban design. The orientation of streets with respect to the dominant wind direction, the size, height and density of buildings, the distribution of high-rise buildings among smaller ones and street width all affect wind conditions (Givoni, 1998). In fact, this was already noted down by roman architect Vitruvius, who considered the direction of streets essential to prevent cold and moist winds from the streets. The combination of elements that affect wind flows is complex, and the urban design elements should be arranged according to local need. In colder climates, roads (and along it the buildings) that are positioned perpendicular to the dominant wind direction cause the primary air flow to go above the buildings rather than against their walls - which means they will lose less heat. In hot climates, the opposite is necessary to allow for natural ventilation and hence, a diminishing of energy used for cooling.

Orientation of streets is of special importance in urban designs attaching buildings to the street. Street-bound urban design has dominated for centuries, until the functionalism approach took over from the 1930s onwards and 'liberated' the buildings from being attached to the streets. Thus, for decades buildings were situated in park-like layouts with living rooms and balconies or gardens thoroughly oriented towards the sun. To day, urban planning schemes are less dogmatic, allowing for a certain revival of the street-bound urban development schemes. As can be seen in Figure 2.17, according to the functionalist approach, all buildings were situated with optimal solar orientation, thus 'liberated' from the streets. Streets are replaced by internal acces roads and footpaths.

Figure 2.17. The Blidah Park, 1933-34, Copenhagen: example of a functionalist lay-out of buildings.



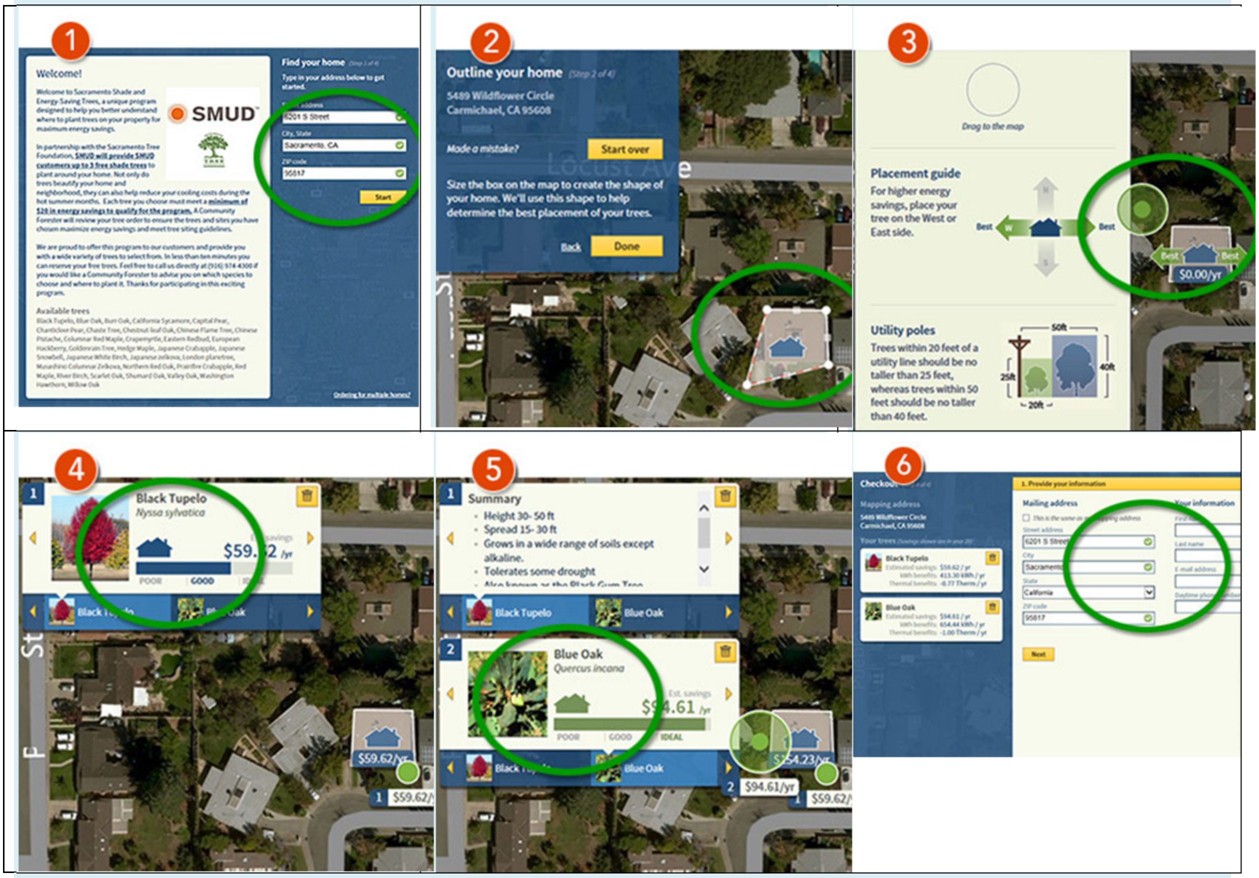
Street-bound as well as park-situated site planning is represented in all the PLEEC cities. For instance, in Eskilstuna, urban development in the center, notably the 'renaissance town' is dominated by the ortogonal street grid. Residential development during the 'million program' after the Second World War was dominated by the park-layout of the new self-contained communities. Finally, the current redevelopment of the central parts of the city is very much depending on, as well as profiting from the historical urban street lay-out.

Open space

Properly sited trees can reduce both the need for cooling and the need for heating. By blocking cold winds, buildings can be kept warmer. And through shading, they can prevent the use of energy for cooling, see the box on the Sacramento Shade program. They also can modify wind flow. It is important to plant the right tree in the right place, and this depends on their growth rate, their crown shape and whether or not their leaves fall off. Selecting the right tree is a key feature of the Sacramento Shade program. It makes no sense to plant a tree to the south of a building located in a cold climate. Proper tree planting, however, can save up to 25% annual energy costs for a household, across a range of climate, house and tree conditions (Heisler, 1986, cited in Ko, 2013). In the case of cold winds, the combination of deciduous and evergreen trees, planted with a moderate to high density in an arrangement perpendicular to the wind is the best solution (Ko, 2013). Deciduous trees have the advantage that they provide shade during hot summers and allow solar radiation to pass during the winter.

Example: The Sacramento Shade program

The aim of this programme is to let house owners make their home cooler and more energy efficient with free shade trees. The programme is funded by a local electricity company, the Sacramento Municipal Utility District (SMUD). It offers residents an excellent online tool (http://energysavingtrees.arborday.org/?partnerCode=07119#Start) to select the right type of trees for their location, get advice on siting them on their property. The trees are delivered to them free of charge within a couple of days. When the trees mature, it is expected that energy consumption for cooling in summer may be reduced by up to 40%.



Source: SMUD
https://www.smud.org/en/about-smud/news-media/news-releases/2014/2014-10-01-Shade-Tree-locator-tool.htm

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Urban form and climate

There are complex trade-offs between urban forms and climates, which means that there is no universal ideal urban form. The importance of local climate translates into different guidelines for reducing building energy consumption. “Climate responsive design” can be considered an emerging field that studies the fields of climate, biology and ecology and combines it with urban scale master planning and building design. One of the aims, next to sustainability, is the reduction of energy consumption in buildings. The following Table 2.3 is taken from Ko (2013) and lists the main issues in each climate.

Table 2.3. General principles of climate responsive urban design (Ko, 2013)

	Hot and Dry	Hot and humid
Reference regio (in U.S.) and city	Southwest (Phoenix, AZ)	Southeast (New Orleans, LA)
Climate description		
Comfort level (percentage of the year)	Too hot for comfort: 37% Too cool for comfort: 48% Comfortable: 15%	Too hot for comfort: 52% Too cool for comfort: 36% Comfortable: 12%
Major climate challenges	Excessive dryness with high dry temperature	Excessive heat and humidity
Housing form and community layouts		
Major design strategies	Solar control	Natural ventilation
Site	South to southeast slopes, flat lands, shallow north slopes	South, north, or any direction; gentle slopes, flat land
Housing types	Compact “patio” house type, townhouse, or apartments	Individual high buildings
Compactness	Compact form	Dispersed form with open ends
Street orientation	East-West with 25° variation to southwest	East-West with 25° variation to southwest
General layouts	Narrow winding roads; uneven building heights; small, dispersed and protected open spaces	Wide streets and open space; uneven building heights
Vegetation	Deciduous trees in the south; trees to the east and west of the buildings; shaded and vegetated surface	Extensive shadow with mature deciduous trees to the north of buildings; some lightly twigged deciduous trees to the south of buildings; shaded and vegetated surface

Source: Ko (2013), in turn based on the American Institute of Architects Research Corporation (1978), Erley and Jaffe (1979), and Golany (1996).

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Table 2.3. General principles of climate responsive urban design (Ko, 2013) - CONTINUED

	Cold and Dry	Cold and Humid
Reference regio (in U.S.) and city	Great Basin (Ely, NV)	Northeast (Hartford, CT)
Climate description		
Comfort level (percent-age of the year)	Too hot for comfort: 0% Too cool for comfort: 92% Comfortable: 8%	Too hot for comfort: 13% Too cool for comfort: 75% Comfortable: 12%
Major climate challeng-es	Strong cold wind	Extreme cold in winter, windy, high precipitation
Housing form and community layouts		
Major design strategies	Wind protection	Wind protection
Site	Lower, sheltered, and gently south to southeast slopes	Sheltered sides on gently south-facing slopes
Housing types	Townhouse or apartments	Townhouse or apartments
Compactness	Compact and clustered form	Mix of open and enclosed form
Street orientation	East-West	East-West with 10° variation to northwest and 25° variation to southwest
General layouts	Narrow winding roads; even building heights; small, dis-persed and protected open spaces	Mix of open and protected open spaces; even building heights
Vegetation	North of the buildings; short or deciduous trees acceptable to the south of buildings	Deciduous trees in the south; ever-greens to the north; low shrubs and hedges to divert winds

Source: Ko (2013), in turn based on the American Institute of Architects Research Corporation (1978), Erley and Jaffe (1979), and Golany (1996).

Another example of a good planning strategy can be found in the UK, and concerns the redevelopment of a former Hospital area, Graylingwell Park. Next to planning and design measures integrating much of the findings above, it is also clear that it is the combination with technological and behavioural changes that is the strength of the project.

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Graylingwell Park, UK.

Source: John Thompson & Partners.

According to the UK Green Building Council, who did a case study of the site, the project is carbon-neutral:
"Graylingwell is an 85-acre former hospital site, that offers 750 new and converted homes along with nearly 8,000m2 of commercial and community amenities including: artists' studios, allotments for residents to grow their own food, a farm shop, gallery space and office space - all managed by a Community Development Trust.
WSP devised an energy strategy which uses a combination of energy efficiency in buildings, photovoltaic panels to offset emissions from combined heat and power - plus a 40% CO2 offset offsite – which makes Graylingwell Park one of the first developments in the UK to be net zero carbon.
The first phase of 110 homes is already completed as well as the energy centre next to a converted Victorian water tower which houses the Combined Heat and Power (CHP) boiler flues. Many of the new homes have photovoltaic roof panels and high levels of insulation. Heating is provided by the central heating and power plant, all appliances are energy efficient and the homes are expected to use around a third less water than usual.
The design of the houses is clearly a crucial element of the energy strategy. The orientation and distance between building has been carefully balanced to maximise the benefit of solar exposure and daylighting for every dwelling and the solar radiation on the roof mounted PhotoVoltaic [PV] panels. The properties embrace energy efficiency measures including, in addition to optimised orientation, super insulation and air tightness levels, and passive heat recovery ventilation.
Aim is to encourage alternative means of transport through walking, cycling, buses. Residents are encouraged to make the most of cycle routes and car clubs provided to preserve this 'green' environment.
Increase accessibility through the implementation of a Green Travel Plan."

This project has won many sustainability awards.
Source: John Thompson & Partners, and www.ukgbc.org.

2.4 Conclusion

Energy use in buildings accounts for the largest share of energy consumption. Following a steep increase, some five years ago residential energy consumption levels stabilized and since then, a decrease can be witnessed. Technological change has been a key driver, but at present, spatial developments such as the increase of volumes of houses, offset the gains deriving from technology to some extent. However, urban form has the potential to further reduce energy consumption in buildings – a potential that seems far from being fully utilized in European cities.

Planning has an indirect influence on energy consumption in buildings as it affects the local microclimate. This microclimate in turn has a major influence on what is the largest purpose of energy use in buildings, namely space heating. A review of the literature learns that another major part of consumption is for space cooling, especially in the U.S. and in warm climates, but in Europe a comparatively minor share of building energy-use is for space cooling. Cooling is a marginal phenomenon in the PLEEC partner cities. Densification and narrow alleys are generally proposed as a strategy to keep out the heat in warm climates, but in temperate climates these could have an adverse effect as this may provide for more shading and less solar access, important elements of a strategy to limit energy use for space heating (and local generation of energy). The (almost) absent need for cooling also places discussions on for instance the urban heat island effect in a different perspective. While it is considered to be negative for several reasons, including health, from the energy perspective it probably reduces consumption in buildings.

Urban planning predominantly has the potential to reduce building energy consumption through limiting the need for space heating. Potential strategies of municipalities could focus on:

- Optimising solar access of buildings by orienting their long side and windows to the south;
- Orienting streets right: those that are oriented east-west generally improve solar access for the buildings that are aligned;
- The spacing of buildings must also accommodate solar access – which makes that there are limits to certain types of densification;
- However, a well thought out planning maximizes solar access and at the same time allows for multi-family dwellings. Apartments tend to be more energy-efficient than detached houses;
- Protection from cold winds will generally be more important than wind ventilation in warmer periods. To do so, buildings can be positioned in such a way that they block winds, making that air flows above the houses instead of between them;
- Equally important is the blocking of cold winds through tree planting. Positioning trees right is very important and may make a big difference in heating energy consumption. Deciduous trees can be used in humid and cold climates where shading in summer is useful, but solar access in winter is required too. Planting evergreen trees to the north is a safe bet;

What our research highlights is that each city demands another mix of strategies that is tailor-made with respect to the local climatic conditions.

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Many of these strategies can be applied when adapting the existing urban fabric. Likewise, new urban developments or brown field regeneration also provides ample opportunities for reducing building energy consumption, as the various examples have shown.

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3 Industrial energy use and urban form (Arie Romein)

3.1 Introduction

Next to transport and households, industry is one of the three largest energy consumers in European cities. For the EU-27 as a whole, it is the third largest user after residence and transport (Figure 1.1), but this order may be different across EU countries, regions and cities. In a historic perspective, energy use by the industrial sector has fluctuated most probably more than use by the other two major consumers. The 'classic' manufacturing industry of large-scale corporate firms processing raw materials or mass-producing a limited range of goods was a large energy user until approximately the mid-1960s. In the subsequent 25 to 30 years, many western cities were hit by a process of de-industrialisation and a severe economic and social crisis in its wake, going together with decreasing industrial energy use less. Since the mid-1990s, then, a trend that can be characterised as urban reindustrialisation (e.g. Hutton, 2010; Scott, 2012) has taken place due to recovery of industries, in new shapes, that survived the 1970s and rapid developments of various new types of industries, in particular knowledge-based, creative and cultural industries. This trend would have gone together with increasing industrial energy use. Besides, it has been accompanied with a substantially broader diversity of the industrial sector, and a greater diversity of industrial location trends. By and large, large-scale manufacturing industries are found mainly at the edges or outside the built-up areas of cities, while most new industries (and services) tend to cluster in central areas of cities.

Overall, urban form includes a range of features of the built-up urban environment, including density and compactness, mix or diversity, clustering and design. In common with energy use by the transport and residential sectors, planning policy defined as interventions in urban form, are only one of a variety of energy-saving measures that also includes non-spatial policies, human behaviour, and investments in new energy-saving technologies if economically feasible for companies (Taibi, et al, 2011). On the other hand, "spatial planning sets frameworks for energy consumption, production and distribution", either consciously or accidentally (Stoeglehner et al., 2011: 1). Altogether, then, spatial planning policies play a role in reducing energy consumption by industries, and should even play a major role in transformations from fossil point resources to more distributed renewable resource systems.

Notwithstanding the importance of spatial planning for industrial energy use, part of this role deals with energy use by industrial buildings, i.e. with their size, type, orientation and configuration, and with open space in these buildings immediate environment, hence coinciding with Chapter 2. This chapter focuses primarily on the second component of industrial energy-use, i.e. for production processes. Nevertheless, if planning policies with regard to urban form is restricted to polices influencing locations of industrial activities, these can have considerable impacts on these activities' energy use.

This chapter starts with 'setting the scene', i.e. brief abstracts of observations in the case study reports about industrial energy use in the six PLEEC cities. Next, section 3 places these observations in the context of trends in energy use and efficiency since the year 2000 both in the EU as a whole and in the separate 'PLEEC countries'. Michaelis & Jackson (2000: 209) concluded in 2000 that "moving towards sustainable development in the primary resource industries represents a formidable challenge": both the overall European trend and national trends show some successes in this regard. Dealing with trends on national level, this section can be skipped by readers who want to stay on the city level. Those can move directly from the case study cities to relations between urban form and planning with urban industrial energy use starting in section 3.4. Based on a review of some literature, this section deals with the role of urban locational factors in industrial energy use and efficiency policies. The conclusion of this section can be twofold, either urban form really does not matter, or policies to reduce industrial energy use leave a valuable instrument unutilized. Section 3.5 elaborates on these two possible conclusions by working out the relationships between urban form and industrial location in two different types of urban locations, i.e. central and peripheral locations. Because industrial symbiosis is a key concept in that section, section 3.6 presents a brief case study in the Netherlands of industrial symbiosis. The final two sections 3.7 and 3.8 present preliminary recommendations for future planning policy regarding urban form in relation to energy use and concluding remarks.

3.2 Industrial energy consumption in PLEEC cities

The case-study reports of the six PLEEC cities pay considerable explicit attention to energy use (and efficiency) by the residential and, more in particular, the transport sector, but make this issue hardly explicit for the industrial sector. If this means that industry plays at best a secondary role in the current debate and policy-making on energy efficiency in these cities, this would be an omission given its considerable share of urban energy use in general. What is more, in a world-wide overview of energy efficiency and conservation policies, Tanaka (2011: 6532) takes as a basic assumption that "Industry's large energy use and vast potential for energy savings make it an attractive target for improving energy security and climate mitigation through increased energy efficiency". This section summarises the information of industrial energy use that is presented in the six reports.

Jyväskylä

Going together with a decline of the traditionally dominant type of industry in its area, wood-pulp production, the municipality of Jyväskylä initiated, in 1985, a partnership with the local University of Applied Sciences to promote the growth of an ICT-based industry. Hence, the city is characterised by an explicit long-term policy to transform towards a growth centre of high-tech industries, including further development of its education and knowledge infrastructure. Recently, the wood-pulp industry has recovered and reinvented itself to some extent. It is now seen as a core industry again, including the coming about of cross-overs with high-tech industry.

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Overall, the city's energy consumption tends to increase. This might be related to the recovery of traditional industry, but the responsible processes mentioned in the case study reports (Read & Hietaranta, 2015) only indicate growth of demands for energy by transport and household– in particular suburban dispersal of residence, demographic changes and increasing wealth. What is more, Jyväskylä has witnessed a 'post-industrial reduction in energy use' due to both its transformation towards a knowledge-based industrial centre (including a former Nokia R&D centre which initiated numerous startups) and introduction of energy efficiency technologies in industrial processes.

Eskilstuna

The modern industrial development of Eskilstuna dates back to the mid-19th century and was primarily built upon steel and metal tools production. In the 1960s, the municipality facilitated the relocation of industrial enterprises from the city centre to new industrial zones and bought obsolete industrial premises closer to the town centre in order to start an urban renewal programme that involved their transformation into offices and shops. This programme came to a standstill, however, due to the de-industrialization process in the 1970s and related economic problems. Eskilstuna's post-industrial economic restructuring policy has been aimed at attracting new types of service industries, and further integrating the city into the enlarging Stockholm regional labour and housing markets.

Data about energy use is only provided for Södermanland region around Eskilstuna. According to data in the case-study report (Groth, Große, & Fertner, 2015), transport, households and industry consume respectively 30%, 28% and 20% of the total final energy use; the remainder being used up by other services, public enterprises, primary sector and some losses. The shares of the three main consuming sectors may be different for the city, but their order is mentioned to be equal: most energy is being consumed by households and least by industry. It appears, however, as if the by far largest energy consumer in Södermanland - the huge steel plant SSAB in Oxelösund - is not included in these figures. For, figures of 2008 show rounded off shares of 19% for both transport and residence and services against 64% by industry if this plant is excluded (Södermanland lan, 2008). Of these 64%, three quarters is consumed by SSAB. Regarding the sources of energy for heating, district heating contributes to 65% of the total consumption, but only 10% for heating of industrial buildings. In contrast, electricity account for three quarters of the energy used in industrial buildings.

Santiago de Compostela

In Galicia, industrial development started only very recently. In fact, it received a decisive boost from European structural funds and made great progress only in the 1990s. Its total final energy consumption increased from about 5000 Ktoe (Kilo tonnes of oil equivalent) in 1997 to 7000 in 2008, and dropped again to 6400 in 2009 when the economic crisis became apparent. Notwithstanding its late start, industry is now the largest single energy consumer in Galicia, using almost half (47.4% in 2009) of the regional total. Over half of this total consumption is generated by oil products (53.6%), over a quarter by electricity (27.6%), and the remainder by renewable energy (11.3%) and natural gas (7.4%).

The current main industrial branches in Santiago are timber processing, automotive industry, and telecommunications and electronics. The economic base of the city, however, rests first and foremost upon three non-industrial pillars, i.e. education, culture and religion, and public administration. Since Santiago became the capital city of the autonomous community of Galicia, consisting of four provinces with Santiago located in A Coruña, the latter pillar includes the Galician government, parliament and quite a few public institutions. Data about energy consumption by sector is not available for the city, but the share of its small industrial sector may be expected to be below the regional figure (Fernandez Maldonado, 2015).

Stoke-on-Trent
Stoke-on-Trent is located in the heartland of the world's first Industrial Revolution in the 18th and 19th century and has an industrial history that dates back about two centuries, further than of any other PLEEC city. Due to the presence of several raw materials including coal and clay, the city and its surrounding North Staffordshire region developed into a major cluster of ceramics production, including world famous brands like Wedgewood. The main causes of its rather sharp industrial decline in the third quarter of the past century were a loss of competitiveness of local industry and, secondly, exhaustion of its regional resources. The PLEEC case study report (Rocco, 2015) does not contain any information about energy use of the ciy's industrial sector.

Tartu
Although industrial development in Tartu started to grow notably during the 1870s, much of the city's industrial history was shaped during the half a century of the Estonian Soviet Socialist Republic. Towards the end of that period, Tartu gained a noteworthy share of about 10 % of the SSR's industrial production, especially due to machine and equipment building, and light industry. As one of the SSR's, Estonia was not affected by the de-industrialization process of the 1960s and 1970s. Instead, the closure of many industries and hence the loss of a large number of jobs followed the breakdown of the USSR and Estonia's independency in 1991.

After 1991, economic restructuring has made Tartu into an urban centre of public administration, service industry, trade and tourism in southern Estonia. Hence, Tartu has relatively few jobs in industry compared to Estonia as a whole: 12% versus 22%. As a consequence, industrial energy consumption is also relatively limited. The proportion of total energy consumption in 2010 by transport was 24% and by households 42%. The reminder 34% was the total of the entire business sector, of which industry is only a limited part. The contribution of industry to the total emission, 5%, was even extremely low (Große, Groth, Fertner, Tamm, & Alev, 2015).

Turku
Turku became an important industrial town in Finland during the 19th century. It has neither escaped, however, the processes of decline and transformation of the industrial sector in the second part of the 20th century. Still recently, in 2012, 850 jobs were lost in the Turku region due to the closure of the Nokia production plant in Salo, at about 50 km east of the town. Today, industry contributed 14% to total employment in the city; a proportion below the 18% in Finland as a whole. Data on the share of total energy consumption by the industrial sector are lacking, but the case study report (Fertner, Christensen, Große, Groth, & Hietaranta, 2015) comments that it is a 'big customer' of the district heating system, making this system feasible.

Comparative perspective: Chinese cities

Compared to the PLEEC cities and European cities in general, industrial development and energy use show a highly different and rather extreme picture in Chinese cites. Many have only recently gone, and still go through a very rapid process of industrialization and pay limited policy attention to energy efficiency and carbon emission reduction. According to Shao et al. (2014: 590), Chinese cities are characterised by "low efficiency and high-emission industries". Both the rapid industrialization and low energy efficiency lead to industrial shares of total energy consumption that are, in general, larger than in Europe. In Shanghai, for instance, this share amounted to 42.7% in 2010 (Zhang & Guo, 2013: 1367). The large industrial share is even more notable if compared with residential energy use. For the decade 2000-2010, it was about three times as large as residential consumption in Beijing – the capital city with a relatively large administrative and service sector - and even about six times as large in Shanghai (cf.: 1367). Although these two cities are hard to compare with the medium-sized PLEEC cities with regard to size, it is highly likely, given the above quote by Shao et al. (2014), that industry in smaller Chinese cities also consumes a larger share of energy than in PLEEC cities. This may indicate that industrial energy consumption in the PLEEC cities has decreased in the course of time, with deindustrialisation and the shift of industrial production to low cost countries.

3.3 Trends in EU and PLEEC countries

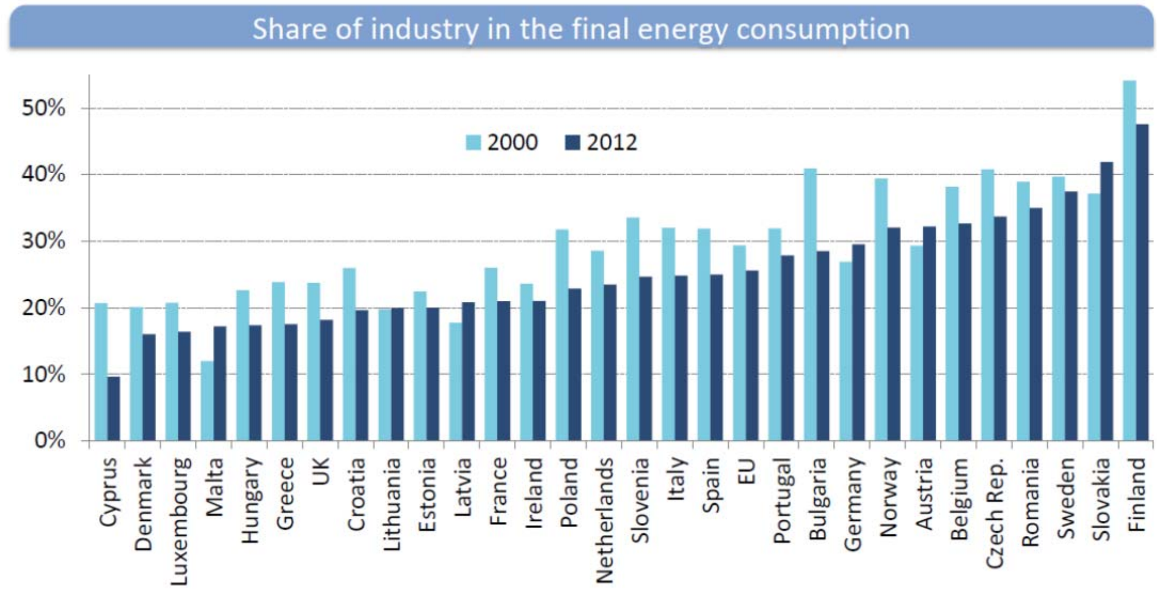
Unless specified otherwise, the data for this section are supplied by the project ODYSSEE MURE (2012 and 2014) that explores trends in parameters of energy use by industries between 2000 and 2012 in the EU-member states. The industries included are the 'traditional', usually very large-scale industries chemicals, paper, steel, machinery, food, non-metallic, non-ferrous, transport vehicles, textile and wood. The section focuses on respectively final (total) energy use and energy efficiency and intensity, and pays special attention to impacts of the economic downturn that started at the end of the past decade. These issues are discussed for both the EU as a whole and for the five countries of the PLEEC cities. Energy efficiency and intensity are strongly related units, measuring the number of units of energy needed respectively per unit of final product, for instance one tonne of steel or paper, and per unit of GDP.

Final energy use

Final energy use by industries in the EU decreased by 12 % between 2000 and 2010. However, contrasting trends are visible throughout this period: a slight increase of 0.5%/year between 2000 and 2004, a decrease of 1.8%/year between 2005 and 2008, a dramatic drop by almost 15% with economic downturn in 2009, and renewed increase by 4.6 % in 2010. Decreasing energy use by the relatively high energy-intensive sectors metals and chemicals and, in addition, a shift towards less energy-intensive branches is primarily accountable for this overall trend. As a result, the industrial share of total final energy consumption decreased from 29% in 2000 to 24% in 2009, and rose again to 26% in 2012. The minimum and maximum values in the EU were 10% (Cyprus) and 47% (Finland) in 2012 (Figure 3.1). In absolute figures, the decreasing final energy use resulted in a net saving of final energy use of 38 Mtoe (Million tonnes of oil equivalent) in 2010 compared with 2000, and even 47 Mtoe in 2012. The high share of industry in Finland's final energy consumption should also be seen in the light of the country's energy strategy involving use of a renewable forest as an energy source, which due to expanding managed forest are claimed as a net carbon sink.

In addition to the reduction of final energy use, an overall shift in the EU towards use of less polluting energy carriers is visible. Over the period 1990-2012, the share of coal plus oil decreased form 38% to 24%, whereas the share of district heating and biomass increased from 9% to 14%. This latter was outnumbered by the growth of the share of electricity use, from 23% to 31%, whereas the share of the complementing carrier, natural gas, remained almost unchanged: from 31% to 32%.

Figure 3.1: Share of industry in final energy consumption in the EU, 2000 and 2012



Source data: ODYSSEE MURE.

Table 3.1: Industrial share (%) of total final energy use in PLEEC countries, 2000 and 2012

	2000	2012
Estonia	22	20
UK	24	18
Spain	32	24
Sweden	40	38
Finland	54	47

Source data: based on Figure 3.1.

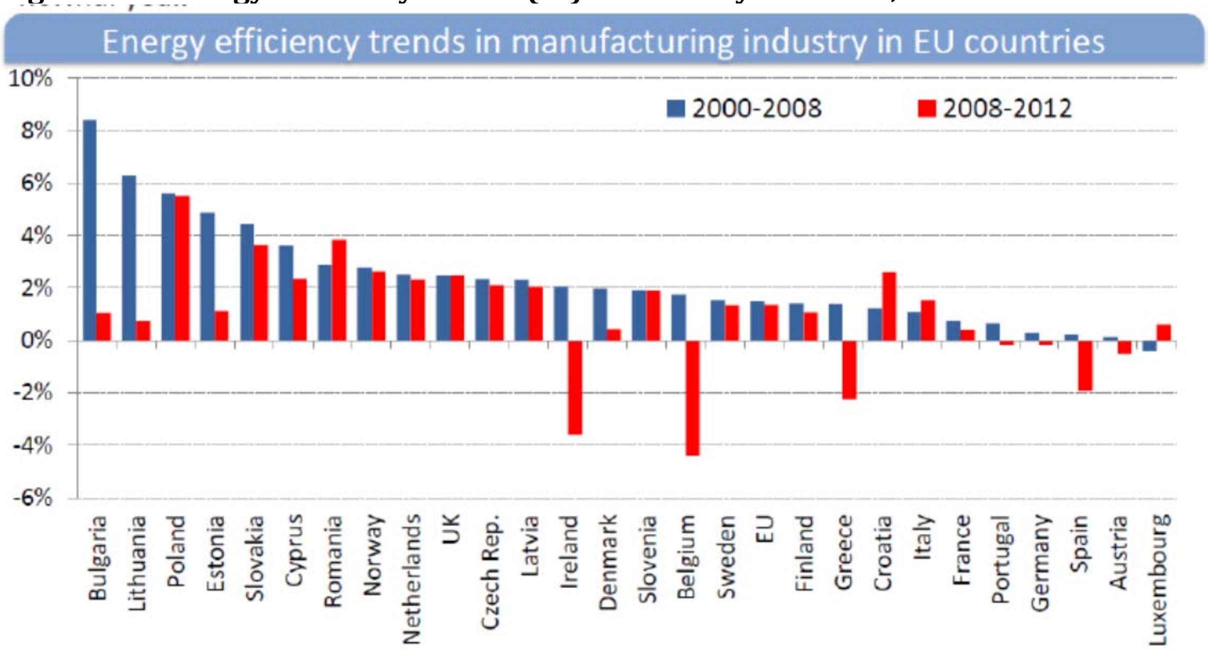
In the five PLEEC countries, the industrial energy use is obviously above EU average in Sweden and Finland (Table 3.1). This may reflect the importance of the energy intensive forest, including pulp and paper, and steel industries in both countries (Nyström and Cornland, 2002: 432; Korhonen, 2001: 369). Compared with the lowest intensity branch, machinery and transport equipment, pulp and paper requires 12 times as much energy per unit of value added, and primary metals (including iron and steel) even 30 times as much.

The trend of the industrial share of total energy use since the beginning of this century is in line with the overall EU trend of decrease in all five countries. In Estonia and Sweden, the decrease amounted to only 2 percentage points, but in the other three countries to 6 to 8 points. The 8% decrease in Spain may reflect the economic crisis that has been deeper of in this country than in the other four.

Energy efficiency and intensity

Industrial energy efficiency in the EU improved rapidly: by 1.5%/year between 2000 and 2008, and by 1.4%/year between 2009 and 2012. The greatest progress in energy efficiency was achieved by the bulk consumers chemicals (-53% between 1990 and 2010) and steel production (-27%). In the case of chemicals, a structural transformation, i.e. a shift to from heavy to less energy intensive light chemicals (e.g. cosmetics and pharmaceuticals), has had impact on this progress, although precise data of its size is lacking.

Figure 3.2: Energy efficiency trends (%) in industry in the EU, 2000-2012



Source data: ODYSSEE MURE.

The overall efficiency improvement in 2000-2008 was part of a longer trend, since average annual improvement amounted to 1.7% between 1990 and 2009. This figure even indicates a slow down of the pace of efficiency improvement since 2000 compared to the 1990s. The slowdown since the end of the past decade is an indication of the general negative effect of economic downturn on trends of energy efficiency of industries: energy efficiency decreases as the effect of operation of plants on less than full capacity due to economic downturn.

Table 3.2: Energy efficiency trends (%) in PLEEC countries, 2000-2012.

	2000-2008	2008-2012
Estonia	4,9	1,0
UK	2,4	2,3
Spain	0,2	-1,9
Sweden	1,6	1,4
Finland	1,5	1,0

EU	1,5	1,4

Source data: based on Figure 3.2

In line with the general trend in EU countries, the energy efficiency improvement decelerated in all five PLEEC countries between 2008 and 2012 (Table 3.2). However, it was significantly larger in Estonia and Spain than in the other three. In Spain, it even reversed towards a deteriorating energy efficiency in absolute figures since 2008, probably an illustration of the relatively sharp impacts of the economic crisis in this country, for suboptimal use of industrial installations is being accompanied with less energy efficiency.

The energy intensity of industry in different countries is a composite of two trends: variation at constant industrial structure and the effect of structural changes in industry. The latter effect is already observed above for chemical industries. In the EU as a whole, structural changes explain around 40% of the decrease of the industrial energy intensity both during the period 2000-2008 and the period 2008-2012. The contribution of the effect of structural changes in manufacturing industry on the total, or real variation of energy intensity in the PLEEC countries was largest in Sweden between 2000-2008 and in the UK between 2008 and 2012 (Table 3.3.). Remarkably, energy intensity increased in Sweden after 2008.

Table 3.3: Impact of structural changes in industry on energy intensity (%/year), 2000-2012

	2000-2008			**2008-2012**		
Country	**Real variation**	**Variation at constant structure**	**Structural effect**	**Real variation**	**Variation at constant structure**	**Structural effect**
	-4,4	-3,2	-1,2	-4,6	-2,4	-2,2
Estonia	-2,0	-2,5	0,5	-3,6	-2,7	-0,9
UK	1,0	0,9	0,1	-3,0	-0,3	-2,7
Spain	-3,6	-3,0	-0,6			
Sweden	-6,2	-2,0	-4,2	4,5	1,7	2,8
Finland	-1,0	-0,7	-0,3	-2,3	-1,5	-0,8
EU	4,4	-3,2	-1,2	-4,6	-2,4	-2,2

Source data: ODYSSEE MURE.

Return to the PLEEC cities

The above national and largely non-branch specific trends of energy use cover considerable variations between cities, due to their specific industrial structures and local and regional context features. However, the case study reports do not present data on trends of energy use in the six PLEEC cities. The overall national data presented above may, nevertheless, indicate a local trend for some of these. Most obviously, it is thinkable that the rapidly increased energy efficiency in both forest and metals industry is observable in the cities where these are important branches, like Jyväskylä and Eskilstuna.

3.4 Role of urban form in industrial energy- efficiency policy

Taking the ultimate objective of PLEEC, planning for energy efficient cities, into consideration, a 'normal way of doing' in this chapter would be to explore first the relationships between urban form and energy efficiency, and second, based on findings of that, the current contributions of planning and policy interventions in urban form to improve of energy efficiency policies. However, due to the main observation from the brief review of literature in this section that urban form does not play any evident role in energy efficiency policies for industry, it will first clarify this observation and then turn to the question if ignoring urban form in energy efficiency policy is justly.

Overall, industrial energy efficiency policies serve both environmental and economic objectives (e.g. Ozturk, 2005; Jacobsen, 2006; Thambiran and Diab, 2011, Tanaka, 2011; Morikawa, 2012; Saygin, 2013). Facing climate change with apprehension, these policies first and foremost aim to reduce the emission of greenhouse gases This is indeed the objective of the 20-20-20 EU objective as a framework of PLEEC project. Second, improved energy efficiency also aims to contribute to energy security and lowering costs for both energy imports and industrial production. A third objective, cleaner air due to reducing emission of greenhouse and pollutant gases, is both environmental and economic in nature as it contributes to quality of life as an amenity of the city that attracts more highly skilled creative and business professionals (e.g. Florida, 2002).

To achieve such objectives, a diversity of planning and policy measures have been outlined and implemented, some on the national and others on the regional or urban level. Thollander et al. (2007: 1575) categorize these measures into three types: economic, administrative and informative policy instruments. The economic type includes financial and fiscal instruments like pricing, taxation, duties and subsidies. Aims of these instrument are, for instance, promoting a shift from fossil fuels to bioenergy or introduction of new, energy-saving technologies. In particular SMEs may require some financial support to introduce such technologies because that means both a large investment and a long period to recoup. Administrative instruments include rules, regulations and acts, for instance on emission. Finally, informative policy instruments are meant to enhance knowledge and information on opportunities to reduce energy consumption. One type is the energy audit to identify such opportunities. Audits are primarily organised for SMEs which have limited resources to employ full-time experts in these fields (Trianni et al., 2013). It needs to be commented in this respect that most instruments serve a general societal interest but that company managers ultimately decide, unless it concerns compulsory or inevitable instruments. In addition, some instruments may cause feedbacks that affect the effectiveness of others. For instance the use of wood chips as waste material from forest industry for power plants in industrial symbiosis systems saves on costs but might increase CO2 emissions.

It is already stated above that it can be concluded from the brief literature review for this chapter that urban form or urban morphology do not play an evident role in policies to improve cities' energy efficiency. Two possible conclusions can be drawn from this observation: urban form really doesn't matter, or actual policies leave it unutilized as a valuable policy issue. The next section elaborates on these two possible conclusions by working out the relationships between urban form and industrial location in two different types of urban locations, i.e. central and peripheral locations.

3.5 Relation between urban form and industrial energy efficiency

In a study on the impacts of urban density on energy intensity of the service sector, Morikawa (2012: 1619) comments that "many studies suggest that energy consumption and CO2 emissions are lower in denser cities. However, previous studies have been confined to the gasoline consumption of vehicles or the energy usage of households. Studies on the commercial sector, including retail and service industries, are scarce". This scarcity also holds for the relationship between urban form, with density as one of its features, and industry. It can be reasoned however, that the relationship between urban form and industrial energy use is a function of type of industry, scale of industrial establishments and location, of which the latter comes closest to urban form. Taking location as the differentiating variable, two types can be distinguished: central and peripheral locations.

Central locations

The 'traditional', usually very large-scale industries such as those included in the ODYSSEE MURE project are, in general, no longer found in inner city areas. Instead, centrally located areas in the city – most typical inner city districts – are the places where the earlier mentioned new types of industries tend to cluster. The reasons why these new cluster develop are various and interact with one another, e.g. a small size of companies; a high density and diversity of people, social networks and urban amenities; and a preference for 'old buildings for new activities'.

In the above mentioned study of the urban service sector, Morikawa (2012: 1621) concludes for Japanese cities that

> "Quantitatively, after controlling for the differences in industry structure, energy efficiency improves by approximately 12% when the density in a municipality population doubles. A large proportion of this figure can be explained by the difference in the intensity of floor space use, but differences in the labor productivity and climate conditions are also contributing factors. These results indicate that the efficient use of energy in large and dense cities is mainly driven by higher factor productivity."

Given the structural transformation towards the urban service economy, this conclusion brings him to the suggestion that "investment in infrastructure in city centres would contribute to environmental friendly economic growth (ibid.: 1617)".

The service sector in Morikawa's study is not identical to the new types of industries as meant above, but there is some overlap, e.g. information and communication industries, FIRE industries, and professional and technical services. Furthermore, Morikawa makes no distinction between central and peripheral locations in cities. Nevertheless, the thrust of his argument appears to hold for these industries in inner cities, at least in Europe where inner cities are usually the urban parts with (still) the highest densities and most intense floor space use. The rather widespread strategy of small scale firms in these new industries to co-locate in multi-tenant buildings or incubators saves energy, compared to the case of working in separate spaces, by sharing heat, light and cool air.

In addition to large manufacturing plants, most large-scale energy producers like power plants also disappeared from inner city areas. Most of the types of energy or energy carriers used by industries in these areas can be transferred over distances on the geographical scales of the city, the city region or larger. This includes electricity that is required for the intense use of ICTs by these industries. Heat however, cannot be transferred over large distances, a reason why the generating capacity for district heat systems requires proximity.

Peripheral locations
As earlier mentioned, large-scale 'traditional' industries, including power plants, are mostly found at the edge or outside the built-up areas of cities. The reasons why these are located in such peripheral rather than central urban locations are both environmental and economic in nature, ranging from nuisance and environmental acts regulations to lower land costs and accessibility by car and lorry. There are quite a few examples of the development of clusters of industrial activities situated in peripheral urban locations that are based on spatial proximity as a crucial feature. From the point of view of energy (and materials) use, such clusters are explained, and inspired, by three concepts that are strongly interrelated: industrial ecology (e.g. Korhonen, 2001), industrial symbiosis (e.g. Jacobsen, 2006; Sokka et al., 2011; Chertow & Lombardy, 2005.) and eco-industrial park (e.g. Côté & Cohen-Rosenthal, 1998). Kalundborg, Denmark, described by Jacobsen (2006: 241) as "a complex web of interactions among five collocated companies and the local community", is a frequently studied showcase of industrial symbiosis. The symbiotic companies include a power-plant, an oil-refinery, a biotech and pharmaceutical company, a producer of plasterboard and a soil remediation company.

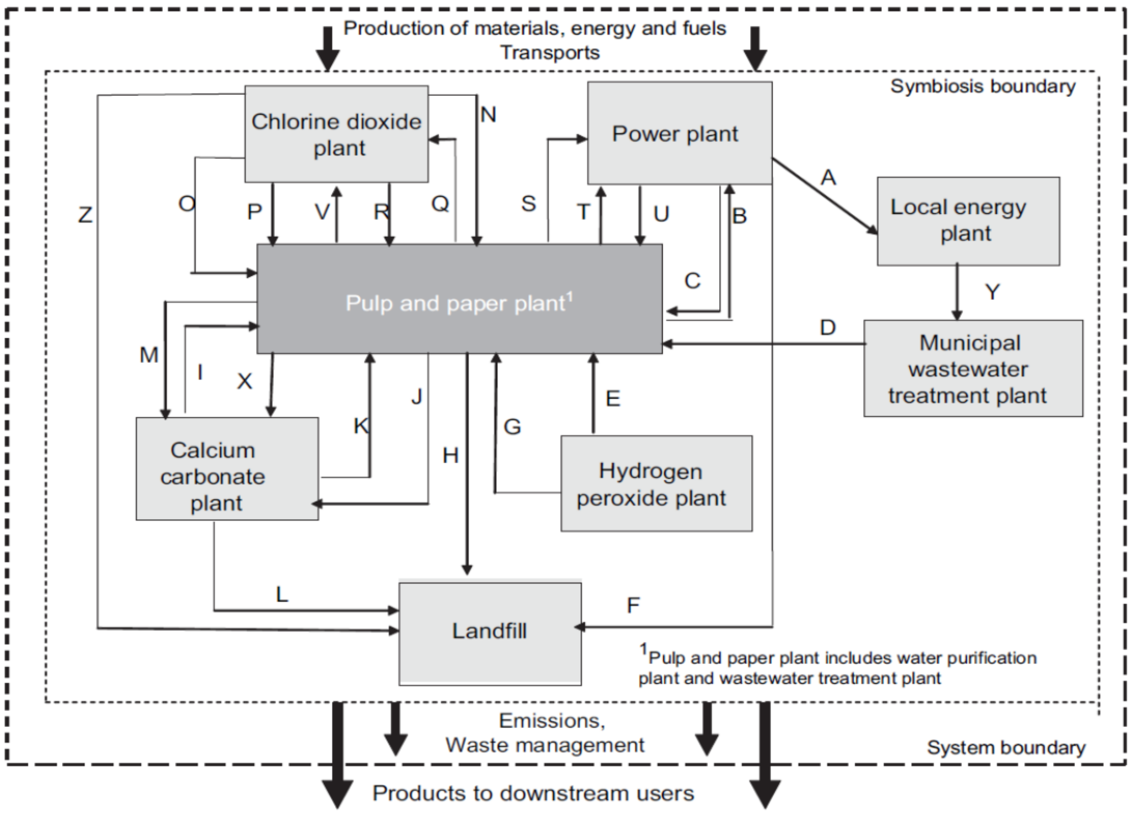
Leaving distinctions between these three concepts aside, their shared overall quintessence is improvement of the efficiency of use of both energy and materials based on 'roundput' (flows) of waste material and waste (residual) energy. This roundput can be organized on the intra- and the interfirm level, but the interfirm level fits in best with PLEEC. Companies, supplemented with other actors including local towns, form a network of suppliers and consumers that mutually exchange waste materials and residual energy, often by-products of suppliers' production processes. These networks are just one, and a relatively simple type of illustration of the observation in Chapter 5 that "energy systems today have developed to a degree of complexity that makes any mechanistic model with simple relations between consumers and producers obsolete".

The benefits of exchanges of energy and materials within such clustered systems are both environmental and economic. Environmentally, they achieve reductions of consumption of 'virgin' raw materials and energy, waste production and emissions on the level of the interfirm network as a whole. Instead of dumping waste materials and greenhouse gases into the environment, these are recycled by selling them to other firms for use in their buildings and production processes. Economic gains on company level include reduced costs for material and energy, waste management, investment in own energy supplying installations, and environmental legislations. 'Reduced material and energy costs' imply that waste is not supplied for free within the system, but it is usually cheaper than purchasing virgin materials. Besides, indirect economic benefits can be achieved from a green image and green markets potentials. In some cases, a power plant – usually the core of industrial symbiosis – would not have achieved licenses to operate without its engagement in a symbiotic network (e.g. Chertow & Rachel Lombardi, 2005).

On interfirm level, a symbiotic system of exchange of different types of energy and materials improves opportunities for co-generation of different types of energy. The combined heat and power (CHP) plant is one of the most frequently occurring type of such co-generation. The most 'natural' type of consumer of CHP is a district energy system (heating/cooling, see also Chapter 5) and the electric grid.

Figure 3.3 presents a scheme of flows of energy and materials in the Kymi eco-industrial park of forest industry in Finland as an example of industrial symbiosis. It distinguishes between no less than 26 different types of energy-carriers and materials that are ‘put round’. It also shows that, in addition to savings due to interfirm proximity within the park, upstream and downstream effects have to be included as well in the assessment of such systems. Upstream, for instance, they save on import, and hence on transport of materials and energy from elsewhere. In addition to savings on energy use by that transport, it also reduces adverse landscape alteration and water use due to extraction of virgin materials (Kaza & Curtis, 2014). With regard to urban form, their proximity avoids the construction of complex networks of pipes, cables and transport across cities. An example of a downstream effect is the heat supplied to district heating systems in nearby local towns (e.g. the towns of Jämsä and Äänekoski near Jyväskylä). Supply of municipal and household waste by these towns to the power plants in the industrial symbiotic system may be, in turn, an upstream effect.

Figure 3.3: Energy and material flows in the Kymi eco-industrial park.



A District heat and electricity
B Sewage sludge
C Wastewater
D Sewage sludge
E Wastewater
F Ash
G Hydrogen peroxide (H_2O_2)
H Miscellaneous inert waste
I Wastewater
J Water
K Calcium carbonate (CaCO3)
L Miscellaneous waste
M Carbon dioxide (CO_2)
N Chlorine (Cl_2)
O Wastewater
P Chlorine dioxide (ClO_2)
Q Water
R Sodium hydroxide (NaOH)
S Sodium hydroxide (NaOH)
T Biomaterials used as fuel
U Steam, electricity, heat
V Steam
X Steam and electricity
Y Electricity
Z Waste

Source: Sokka, 2011: 287

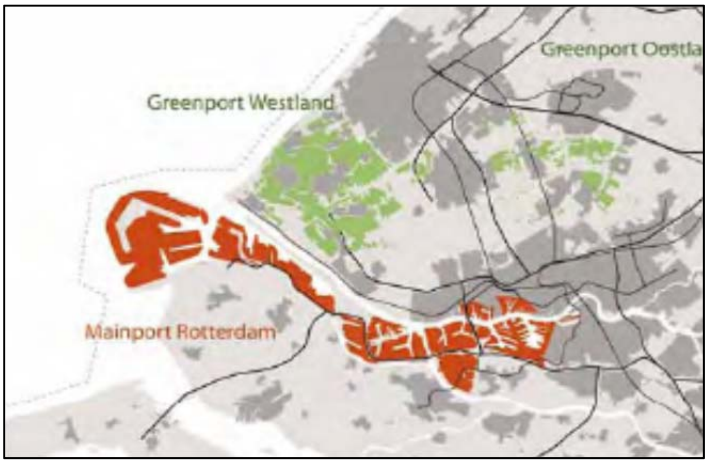
Various authors present quantitative estimations of the benefits of industrial symbiosis. Environmental impact assessment of cases of industrial symbiosis compares the actual size of impact categories with the hypothetical situation that the existing symbiotic relationships are not available. Eckelman & Chertow (2013) distinguish four major impact categories: primary energy use, greenhouse gas emissions (CO2 equivalents), acidification (H+ equivalents) and eutrophication (N equivalents). Sokka et al. (2011) compare the greenhouse gas emissions by the Kymi eco-industrial park that is developed around an integrated pulp and paper plant to two hypothetical stand-alone systems in which actors would operate in isolation. CO2 emissions in these two cases are respectively ca. 40% and ca. 75% larger than the figures of Kymi park. Another example is presented by Korhonen (2001) in a study of the forest industry based symbiotic system in the area of Jyväskylä: CHP in this system creates a total fuel efficiency of 85-90%, whereas this would be around 40-45%in a hypothetical plant that only produces electricity, the rest being dumped as waste, mainly water, to the environment.

To be as successful as most literature suggests, symbiotic industrial systems should meet two conditions. One is about the networks of actors and organisations that are involved and how strategic such systems are for them, the other is about their location First, the engagement of separate firms in such a collective approach demands dedicated management skills in involved firms but more in particular willingness to cooperate in industrial systems. Economic rationale, mutual trust and learning capacity among firms and regional governance mechanisms, all evolved through historical pathways are crucial for the development of successful energy-efficient industrial eco-systems (Baas & Boons, 2004; Eckelman & Chertow, 2014) . More important from the PLEEC perspective, however, is the required co-location of participating firms and residential areas. Physical proximity is required, in particular when energy carriers than can only be transferred over a short distance are included in the flows. This is the case with heat that can be transferred over a maximum distance of 10 to 20 km. (Korhonen, 2001: 373). Hence, the producers of district heat are located close to its consumers. Industrial symbiosis, hence, works best in local or, at the most, regional contexts rather than in larger ones.

3.6 Case Mainport-Greenport

In the Dutch province of South Holland, Mainport Rotterdam and Greenport Westland/Oostland (Eastland), i.e. Europe's largest seaport and the world's largest contiguous greenhouse horticulture complex, are located close to each other (Figure 3.4). Although horticulture is an agricultural branch, its scale and processes in Greenport can be labelled industrial.

Figure 3.4: Mainport and Greenport (West and East) in South-Holland

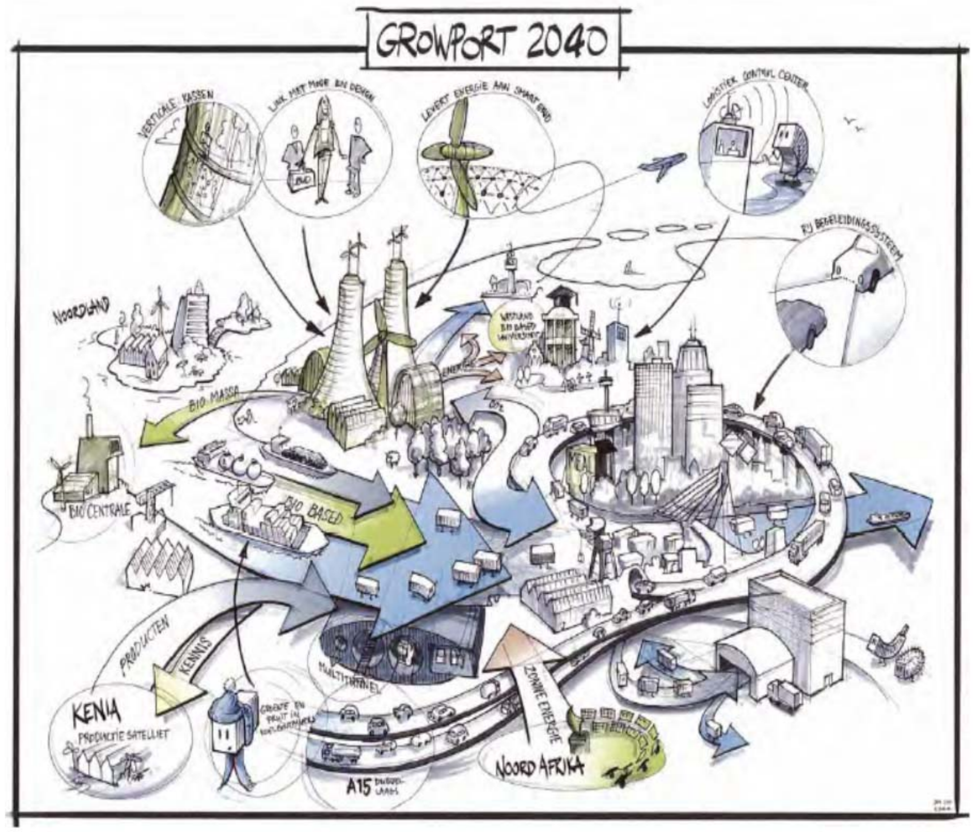


Source: Provincie Zuid Holland, 2011: 30

Basically, these two types of ports are different in many respects and their mutual interactions are indeed quite limited. In the current societal call for sustainable development, however, industrial complexes are not only evaluated by objectives of profit but also of people and planet. In this changed perspective, both port struggle with their image. Most chemical products made in the 'port-industrial complex' (Dutch abbreviation: HIC) of the Mainport are still fossil based. Mid 2000s, electricity production, oil refinery and petrochemical industry together accounted for 80% of the total emission of greenhouse gases and waste cooling water of the whole region of Rijnmond; an area with about 1.25 million inhabitants. But also the activities in the Greenport, including production, national and international trade and distribution of horticulture products use large quantities of energy and produce much waste emission.

In the same perspective of increasing value attached to sustainability, several potentials for innovative interactions between these two peaks of the Dutch economy have been identified as a possible strategy for both to become not only more environmentally sustainable, but also more competitive and innovative. These strategies include the development of a clean bio-based economy, construction of a CO2 and heat network, and mutual use of other residual and waste products such as water and biomass. Hence, the Province started the Mainport-Greenport project in 2009 with the objective to design a long term perspective towards a more integrated 'Growport' in 2040. In the first years of the project, a few other key triple helix partners have joined the project, including Port of Rotterdam and the Delft University of Technology.

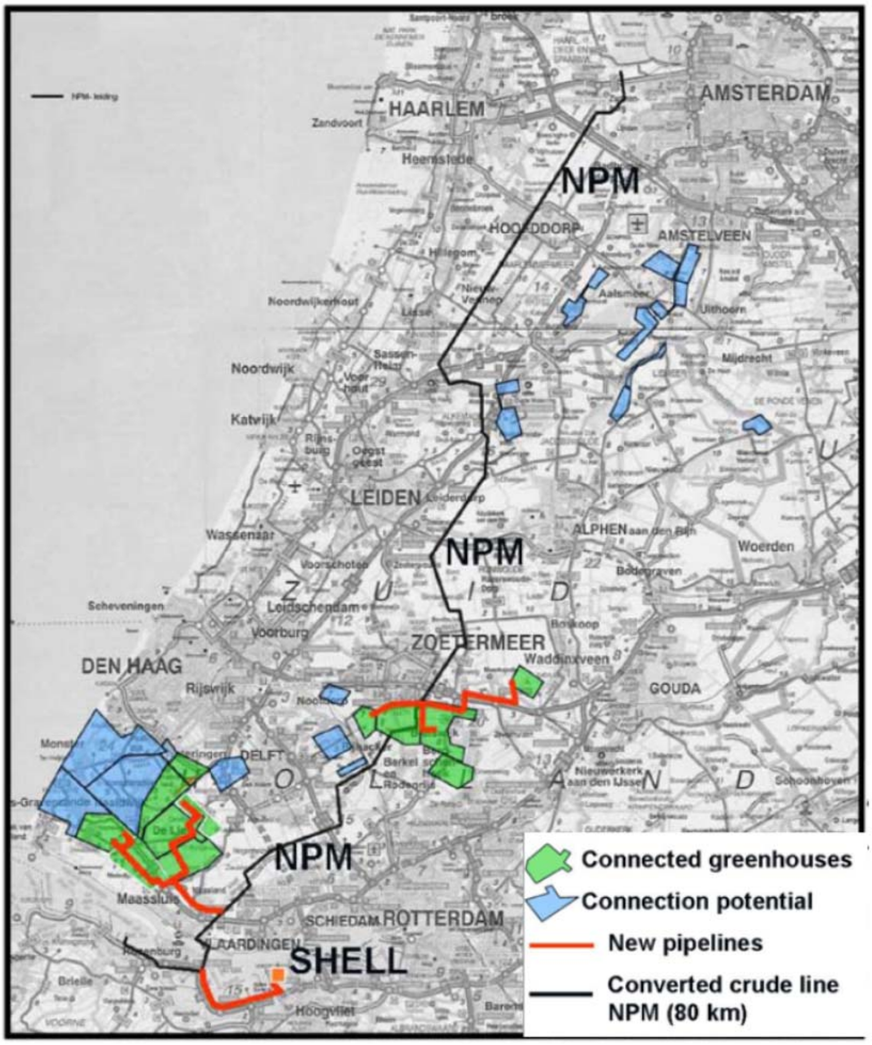
Figure 3.5: Artist impression of the Growport Scenario



Source: Provincie Zuid-Holland, 2011: 2

Since 2005, CO_2 as a residual product of chemical industry in Mainport, is being transferred to greenhouse entrepreneurs in Greenport. CO_2 is a resource for enhanced plant growth in the greenhouses that otherwise would be emitted into the atmosphere. The transfer goes through an old subterranean oil pipeline between Rotterdam and Amsterdam, the so-called OCAP pipeline (Figure 3.6), and newly constructed connections to greenhouse areas. Although a saving of 95 million cubic metres of natural gas and a reduction of CO_2 emission with 170.000 tons per year (Bouman, 2010: 30) in Greenport sound impressive, OCAP supplies only about 30% of its demand and struggles, moreover, with unreliability supply and, as a consequence, a lack of trust in cooperation between businesses at both sides.

Figure 3.6: OCAP pipeline with connected greenhouse areas



Source: Bouman ET AL. (2010: 76)

On-site in Greenport, energy is being produced by combined heat and power installations. Natural gas is incinerated is these installations, its CO2 emission can be used for enhanced plant growth, and other greenhouse and pollutant gases are emitted into the air. In this particular case of industrial symbiosis, CHP contends with mismatches due to seasonal effects. In summertime, the demand for CO2 for plant growth is largest but lowest for heat. Greenhouse owners are now experimenting with mixed forms of the open greenhouse type – ventilation by opening windows means a loss of CO2 into the atmosphere – and the close greenhouse type – practically no loss of CO2 but energy needed for cooling in summertime. Occasionally, the demand for both CO2 and heat is low, but even then CHP stays in operation because of contractual sales of generated electricity to the grid, also a source of income for producers. In fact, oversupply of electricity for the grid is the main barrier for expansion of CHP capacity in the area.

Given the mismatches of the CHP production, de-coupling of heat and CO2 supply and expansion of supplies of both by industries in the Mainport should be both economically and environmentally beneficial for Greenport. One step on this road is the connection, in 2010, of a new bio-ethanol plant in Mainport to OCAP. In addition, interconnecting the different heat suppliers within Greenport into an integrated system would also save costs and reduce emissions, but requires the construction of a network of pipelines through the area.

3.7 Provisional recommendations for planning policy

One of the features to take into account with regard to policy recommendations is the distinction between two main components of energy use by industries: energy to create a comfortable indoor climate for workers in industrial buildings (heating, cooling, lightning) and energy for production processes. The first component is primarily conditioned by characteristics of these buildings as such and of open spaces in their immediate surroundings. Possible interventions in urban form that comprise these buildings and open spaces are highly similar or even coincide with interventions regarding residential energy use, as are elaborated in Chapter 1. One issue that makes a distinction between residential and industrial buildings is the shared use of energy-consuming heating, cooling and lightning. Although the size of the household relative to the size of its dwellings varies, with impacts on energy efficiency – small households in large houses is usually energy inefficient –, the occupancy rate in for instance multi-tenant industrial buildings varies more, and has more impact on energy efficiency. Any public policy to keep the occupancy rate, or the intensity of floor space use as it is labeled by Morikawa (2012: 1621), as high as possible improves energy efficiency. Such policies have, however, little or nothing to do with urban form.

Overall, relationships between urban form and industrial energy use for production processes are hardly elaborated explicitly yet, neither in academic literature nor in urban planning policies in practice. If urban form is replaced with location, however, the concept of industrial symbiosis that is rather strongly related to energy use pops up. This concept opens up a diversity of planning policy recommendations that deal with issues like co-location of industrial companies; construction of energy transferring networks of pipes, cables and the like; and short distances to the local town or city. The concept of industrial symbiosis has indeed features like density, diversity (also functional, i.e. of industrial branches) and proximity, but also (shared) infrastructure (Cuddihy et al., 2005) in common with urban form. As to diversity, the Mainport-Greenport case shows that a uniform industrial structure, in that case of only horticulture, leads to a sub-optimal efficiency of energy use.

3.8 Concluding remarks

Although the relationships between urban form and industrial energy use as such hardly receives attention in literature, it can be concluded that the causality of these relationships differ between the above discussed two types of location. In general terms, urban form impacts upon industrial energy use in central locations while, in the reverse order, industrial energy use impacts upon urban form in peripheral locations. The types of firms in co-located clusters, e.g. paper and pulp plants, CHP plants, chemical plants, sewage plants or even oil refineries, are usually of a size that makes these clusters significant physical nodes in the urban form of municipalities.

Literature that links industrial energy use to urban areas in general, meaning not to urban form in particular, implicitly appears to be highly limited to heavy industries processing raw materials (wood, ore) and producing semifinished articles (steel, paper).

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The new knowledge-intensive and creative industries are ignored. A search action to literature on energy use by creative industries has yielded only one journal paper, about music industry in the UK (Bottrill et al., 2010). Nevertheless, it is suggested by several authors (Ji et al., 2014; Morikawa, 2012) that a transformation towards an urban economy with growing service and creative industries is accompanied with reduction of energy use. Such a transformation is taking place in many cities, although to a different degree, and receive much attention by academic research by economists, geographers, sociologist, political scientists, urban planners and even urban designers, but still not from the perspective of energy use and efficiency. Hence, urban planning polices to achieve reduction of energy use and increase energy efficiency by the industrial sector requires extension of the research agenda at least in two directions: to the link with urban form and to the new types of industries.

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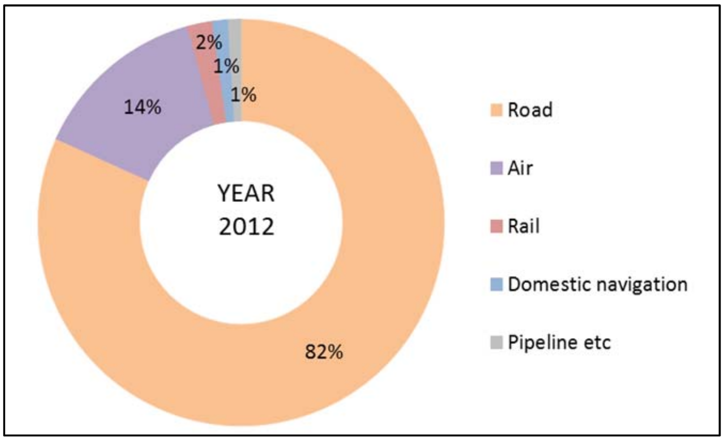
4 Transport and energy consumption (Dominic Stead)

4.1 Introduction

Transporting people and goods accounts for almost a third of all energy consumed in Europe. Approximately half of transport energy consumption in Europe is related to the movement of people (passenger transport); the other half is related to the movement of goods (freight transport). This chapter focuses on the relationships between spatial planning, urban form and transport energy consumption, focusing particularly on the ways in which spatial planning can reduce passenger transport energy consumption by promoting development with more energy efficient urban forms.

Urban development patterns (otherwise called *urban form*) are shaped by spatial planning policies at different scales, ranging from local through to regional and national. Urban form encompasses a range of characteristics including the density, functional mix (or diversity), clustering and design of urban development. Research suggests that urban form can have both direct and indirect impacts on transport demand and energy use. Therefore, spatial planning policies provide a way of influencing the demand for transport and the energy it consumes. Clearly, spatial planning policies are just one of several types of policies (alongside pricing policies, education and awareness policies and other regulations) that have the potential to reduce the energy consumption of transport (Banister at al, 2000). Other types of policies can have more immediate or far-reaching effects than spatial planning policies. Nevertheless, planning policies offer some distinct advantages, including the potential to reduce transport demand and transport energy consumption at source. Spatial planning policies typically have important impacts on transport demand (and energy consumption) in the long term.

Figure 4.1. Breakdown of transport energy consumption in the EU-28, 2012



Based on data from European Commission (2014b)

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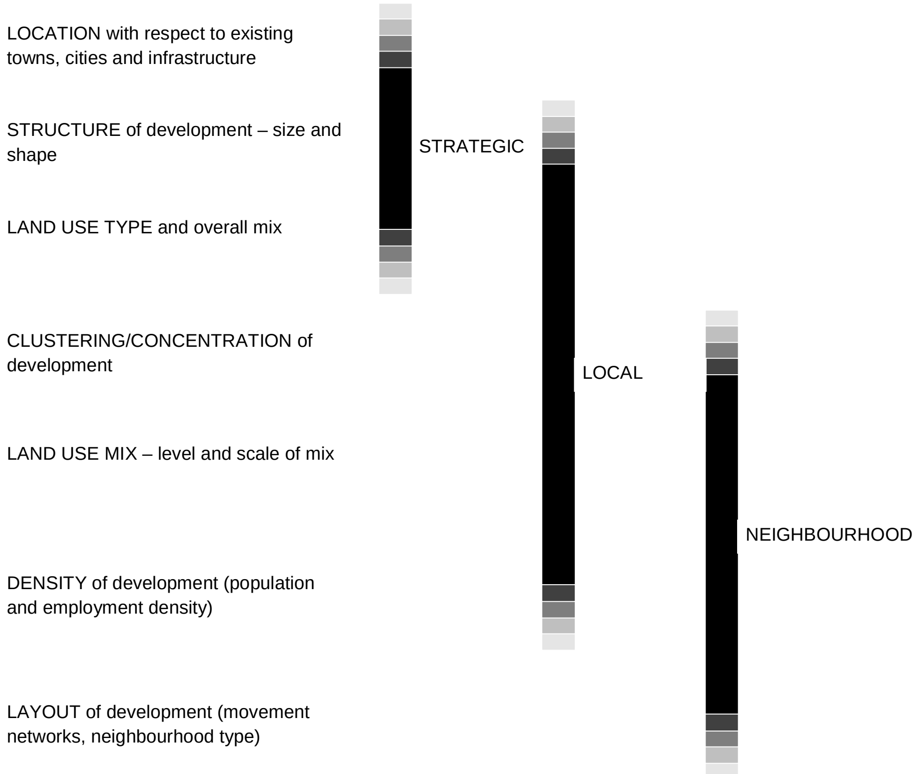
4.2 Relationships between urban form and transport energy consumption

The term spatial planning used in this paper refers to various policy interventions at different scales that influence land use (or urban form). At the strategic level, spatial planning can be used to steer the location of new development in relation to existing towns, cities and transport infrastructure, the size and shape of new development and the type of land use (whether for example it is used for housing, commercial and industrial purposes or a mixture of these purposes). At the local level, spatial planning can be used to influence the density of development, the level and scale of land use mixing and the extent to which development is clustered or concentrated into nodes (Figure 4.2). In this paper, seven aspects of spatial planning are discussed: (i) proximity to existing urban areas and transport infrastructure; (ii) size of development; (iii) mixture of land uses; (iv) provision of local facilities; (v) development density; (vi) layout of development; and (vii) availability of parking.[1]

Figure 4.2. Land use characteristics that can potentially affect travel patterns



Adapted from Owens (1986).

[1] The seven aspects listed are closely related, but not identical, to Owen's typology (Figure 1):

i) proximity to existing urban areas and transport infrastructure is related to Owen's 'location' characteristic;
ii) size of development is related to the characteristic entitled 'structure of development';
iii) mixture of land-uses refers to three characteristics contained in Owen's typology: (1) land-use type; (2) clustering/concentration of development; and (3) land-use mix;
iv) provision of local facilities is related to 'land-use mix' in Owen's typology;
v) development density is related to Owen's 'density' characteristic;
vi) layout of development is related to the 'layout' characteristic in Owen's typology; and
vii) availability of parking is also related to the 'layout' characteristic in Owen's typology.

A range of other typologies of urban form characteristics associated with more energy efficient transport consumption can also be found (see for example Hickman, 2013), most of which broadly reflect the characteristics contained in Figure 1. These typologies often refer to the “3Ds” (density, diversity and design), “5Ds” (density, diversity, design, destination accessibility and distance to public transport) or “7Ds” (density, diversity, design, destination accessibility, distance to public transport, demand management and demographics).[2]

The relationships between land use planning and travel patterns (and transport energy consumption and/or CO_2 emissions from transport[3]) have been the focus of increasing attention in recent years (Transportation Research Board, 2009). There is now a growing body of research concerned with these issues. Studies originate from a diversity of sources, and encompass a variety of geographic scales and locations. In addition, many different characteristics of urban form have been examined in these studies, ranging from regional to local in scale, and travel patterns have been measured in a number of different ways (Stead and Marshall, 2001). Some of the main ways in which land use planning can potentially influence transport demand and energy consumption are summarised in section 3 below.[4]

Almost all empirical studies on the relationship between urban form and transport use are cross-sectional: in other words, they are based on analyses at a single point in time. These often use regression analysis to isolate the variables of interest and hold other variables constant (e.g. demographic and socio-economic characteristics). Although many cross-sectional studies report statistically significant correlations between the built environment and transport demand, they cannot identify causation nor can they provide information about the temporal relations between the built environment and transport demand (e.g. how transport demand will change if the urban form is altered). Establishing causal relationships requires longitudinal research, typically involving panel data in order to follow households (and urban form) over time. Since this type of research is both time-consuming (several decades of data may be needed to observe large enough changes in the built environment) and methodologically challenging (many other variables are also likely to change over time as well), very few long-term longitudinal studies can be found on the relationship between urban form and transport use. As a result, a lot is known about the correlations between urban form and transport use (and energy consumption) but much less about the causalities, long-term changes, and interrelationships between different aspects of urban form.

The issue of scale is an important consideration when analysing the relationship between urban form and transport. As can be seen in Figure 1, urban form can influence transport energy consumption at various spatial scales. For example, local trips (particularly by non-motorized modes) are likely to be influenced by neighbourhood design (e.g. walkability, safety) and the number of desirable destinations (e.g. local shopping, restaurants, schools) in close proximity. In contrast, travel to regional destinations, such as

[2] See for example Cervero and Kockelman (1997), Ewing and Cervero (2001) and (2010).
[3] Travel distance and transport energy consumption are closely correlated (Stead, 1999a).
[4] More detailed reviews of empirical studies concerning these relationships can be found elsewhere (e.g. Badoe and Miller, 2000; Cao et al, 2008; Crane, 2000; Ewing and Cervero, 2001; Handy, 2005; Stead and Marshall, 2001; Næss 2012).

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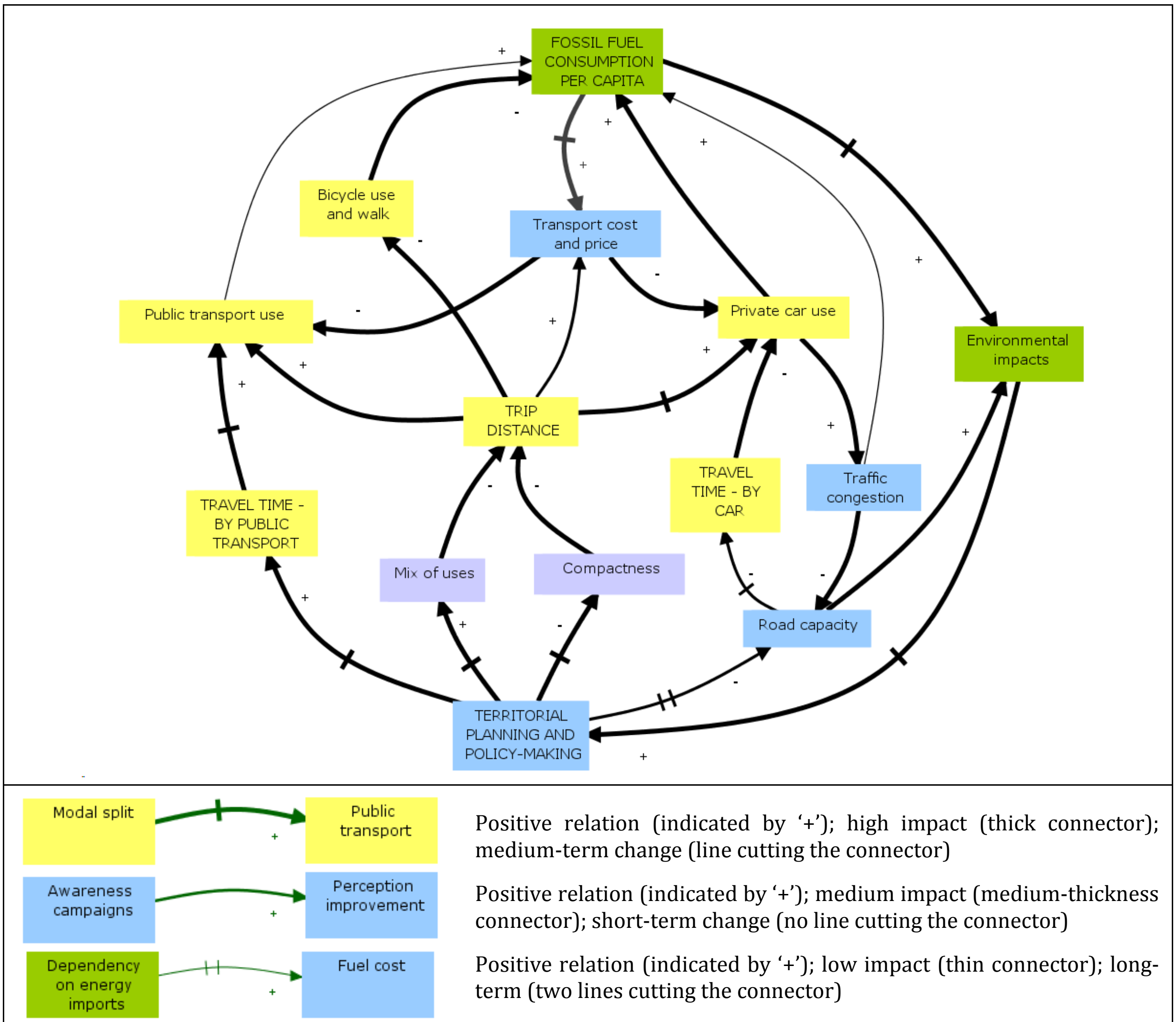
deciding whether to travel by car or public transport to work or a major shopping centre, is primarily determined by the location of jobs or shopping destinations in a region relative to where people live, the accessibility of public transport (at both the origin and destination of a journey), and the time and cost of both travel options (Transportation Research Board, 2009).

Land use patterns are likely to have both direct and indirect impacts on transport demand and transport energy consumption. Conversely, transport demand is likely to have direct and indirect impacts on urban form (Woolley and Young, 1994). Ubach et al (2014) illustrate the complex web of possible interactions (and feedback loops) between spatial planning, urban form and transport energy consumption (Figure 4.3) and show that the relationships between these variables differ substantially in terms of magnitude and timescales (i.e. short or long-term impacts). The figure also illustrates some of the key interactions between spatial planning policies and other types of policies (e.g. public transport, infrastructure and pricing policies) which can also affect the energy consumption of transport.

Figure 4.3. Interactions between spatial planning, urban form and transport energy consumption



Positive relation (indicated by '+'); high impact (thick connector); medium-term change (line cutting the connector)

Positive relation (indicated by '+'); medium impact (medium-thickness connector); short-term change (no line cutting the connector)

Positive relation (indicated by '+'); low impact (thin connector); long-term (two lines cutting the connector)

Source: Ubach et al (2014).

4.3 Practical examples of how planning and urban form can influence transport energy consumption

The ways in which different types of urban form (discussed above) can potentially affect transport demand and energy consumption are summarised below.

The *proximity of development to existing urban areas and transport infrastructure* is closely related to transport energy consumption. In general, transport energy consumption increases as the distance to the nearest urban area increases. Meanwhile, major transport networks can be a powerful influence on the dispersal of both residential and employment development. The proximity to main road and rail networks may lead to travel patterns characterised by long travel distances and higher transport energy consumption.

Settlement size is a key factor influencing the range of jobs and services that can be supported and may influence the range of public transport services that can be provided locally. Small settlements that are unable to support a large range of services and facilities may be less energy efficient due to longer travel distances in order to access services and facilities. However, very large, centralised settlements may also lead to longer travel distances and higher transport energy consumption as the separation between homes and the urban centre increases.

The *mixing of land uses* affects the physical separation of activities which has implications for travel demand and transport energy consumption. The more mixed the land use, the greater the opportunity of activities and services within the immediate area and the lower the amount of energy required for transport.

The provision of *local facilities* and services may reduce travel distance and transport energy consumption by encouraging more locally-based activities and more journeys by non-motorised modes.

Development density is linked to travel demand and transport energy consumption in several ways. Firstly, higher population densities widen the range of opportunities and activities that can be reached without needing to use motorised travel. Secondly, higher densities widen the range of services that can be supported in the local area and reduce the need to travel long distances. Thirdly, higher density patterns of development tend to reduce average distances between homes, services, employment and other opportunities, which reduces travel distance. Fourthly, higher development densities are more amenable to public transport operation which is generally more energy efficient than car transport.

Development layout, including factors such as street design and layout and infrastructure for cycling and walking, can also influence travel demand and transport energy consumption. 'Permeable' street designs, in combination with safe attractive routes for pedestrians and cyclists, can help to reduce journey distances, promote walking and cycling and reduce transport energy consumption (Figure 4.4).

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Figure 4.4. Examples of street layouts with high and low permeability

Source: Hickman et al (2009).

The *availability of residential parking* can affect car ownership and use, particularly if finding a parking space is difficult at a journey's origin or destination. It may also have the effect of encouraging trip chaining and encouraging local journeys by non-motorised modes, especially where there is the prospect of a long search for parking.

Spatial planning not only offers opportunities to reduce the need to travel and but also offers the potential to address the social inequalities of transport. According to Acutt and Dodgson (1996), spatial planning is one of only a few measures that might both reduce travel and also contribute to a more equitable arrangement of activities. Although certain land use characteristics associated with less travel may be complementary with others, there may sometimes be areas of conflict. These can be examined using a causal loop diagram (as illustrated in Figure 4.3) or a simple table such as the one illustrated in Figure 4.5. A number of examples are illustrated in the figure and discussed below – other examples can be found elsewhere (see Stead, 1999b and 2000).

In terms of synergies, mixed-use development is very compatible with the provision of local services and facilities. Higher population densities can increase the number of residents within a short distance of the urban centre, thereby increasing accessibility to the urban centre. Higher density development widens the range of services that can be supported in the local area and is therefore complementary with the provision of local facilities. Greater proximity to the urban centre can be complementary with parking restraint. Lower levels of parking provision can help to support higher densities since less land is required for parking, and higher densities may also encourage more efficient use of parking space (Balcombe and York, 1993).

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Figure 4.5. Representation of synergies and conflicts between land use characteristics

	Proximity to existing urban areas/ transport infrastructure	Settlement size	Mixture of land uses	Provision of local facilities	Development density	Development layout
Settlement size	×					
Mixture of land uses						
Provision of local facilities	×	×	✓			
Development density	✓			✓		
Development layout				×	✓	
Limited parking	✓				✓	✓

✓ represents potential synergy
× represents potential conflict

Adapted from Stead (1999b).

In terms of conflicts, larger settlements may reduce the provision of local facilities (if these facilities are available in the central urban area) unless there are policies to promote mixed use and/or policies to promote short distance trips. Close proximity to transport networks may undermine the use of local facilities locations, particularly in cases where the transport network allows easy access to more distant services and facilities. Close proximity to the main road network may also reduce the potential for limiting parking, since these locations are attractive to car use.

In addition to the synergies and conflicts between different land use characteristics (discussed above), there are a number of complementary policies outside spatial planning, which can help to support and enhance certain land use characteristics that reduce the need to travel. Examples of complementary measures include parking charges and restrictions, vehicle and fuel taxes, road and congestion charging, a reduction of roadspace for cars public transport, priority measures restrictions in car access, and taxation on developments on previously undeveloped ('greenfield') land (see Stead, 1999b). Most of the complementary measures are likely to influence several land use characteristics, rather than one. Some measures may have synergies with certain land use characteristics but not with others. Road and congestion charging, for example, might promote more self-contained settlements, more local facilities and the mixing of land uses but

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may on the other hand discourage development in areas where congestion is most severe (mainly urban areas) and encourage development outside the areas affected by road or congestion charging. This may then lead to increased urban sprawl. Road or congestion charging may also act as a disincentive for some people to live or work in urban areas and increasing the demand for smaller rather than larger settlements.

It is therefore crucial that spatial policies are carefully selected to avoid possible conflicts with other policies. Maximising synergies between different policy instruments is an important consideration when developing spatial policies to reduce transport energy consumption.

4.4 Spatial planning to reduce transport energy consumption in the case study cities

Spatial planning is being employed at different scales to a greater or lesser extent in order to tackle transport energy consumption in all the case study cities. However, the types and scale of intervention differ from city to city. Some plans are much more explicit about the relation between spatial planning, urban form and transport energy consumption. Below is a brief summary of some of the main ways in which spatial planning is being employed in the case study cities in order to reduce transport energy consumption.

In *Eskilstuna*, the 2013 spatial plan for the city region identifies areas for new development primarily based on two urban form criteria: (i) proximity to the existing urban area (and rural settlements) and transport infrastructure; and (ii) development density. Several different sites for development are identified in the plan (Figure 4.6), including urban densification zones (around Eskilstuna and Torshälla), nodal intensification (in Kvicksund, Torshälla, Sundbyholm, Kjula, Hällberga, Årla, Skogstorp, Hållsta, Bälgviken and Alberga) and zones along public transport routes (Groth, Große, & Fertner, 2015). Figure 4.7 illustrates concepts for how the designated areas could be densified.

The 2012 traffic plan for Eskilstuna also makes reference to the links between urban structure and transport energy consumption. It identifies the need to increase density in existing urban areas, to locate new housing in areas connected to the public transport infrastructure, to implement low parking norms, to create an attractive, comprehensive pedestrian and cycle network, and to promote an attractive, effective network of public transport. According to estimates in the traffic plan (Table 4.1), spatial planning offers the potential to reduce road-based CO_2 emissions by 14% in the medium-term (by 2020) and by a similar amount in the longer term (by 2050).

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Figure 4.6. New development areas identified by the 2013 Eskilstuna spatial plan

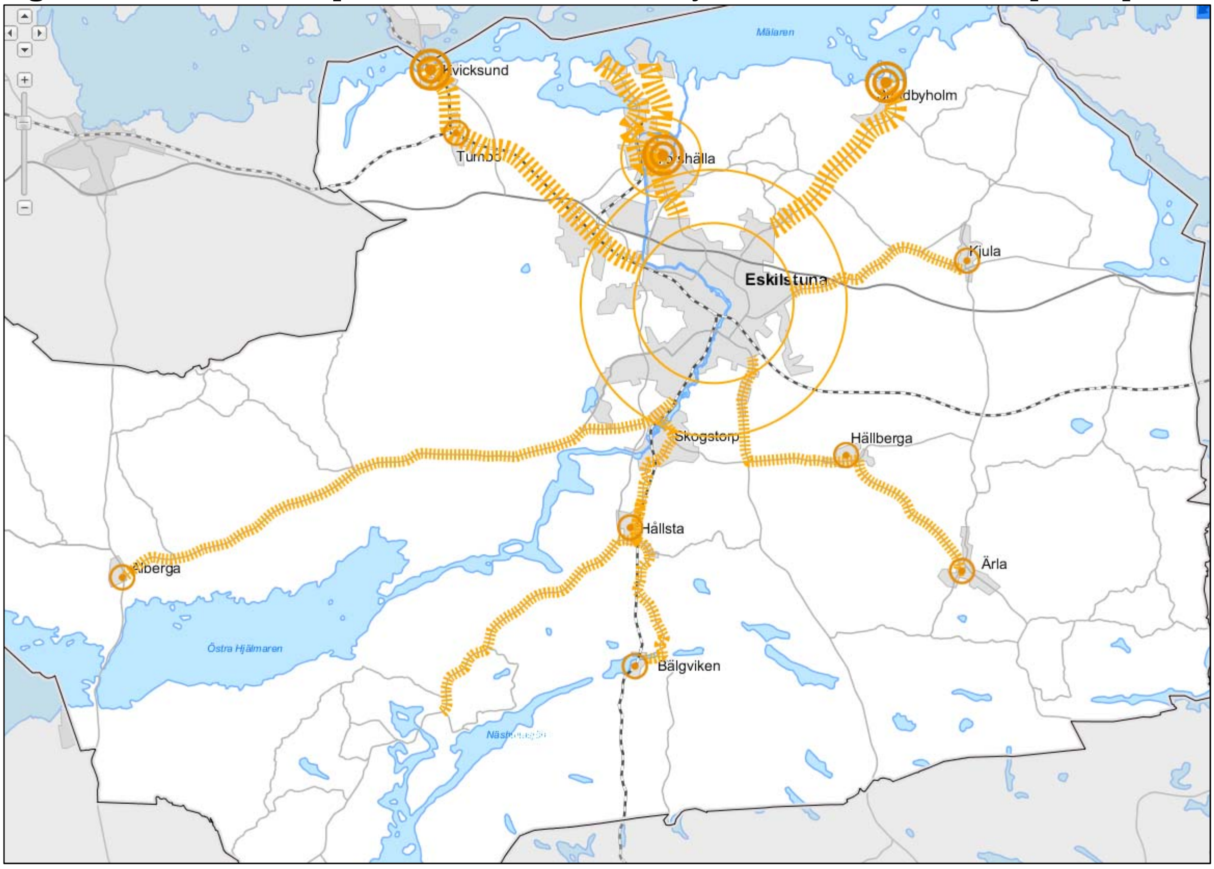
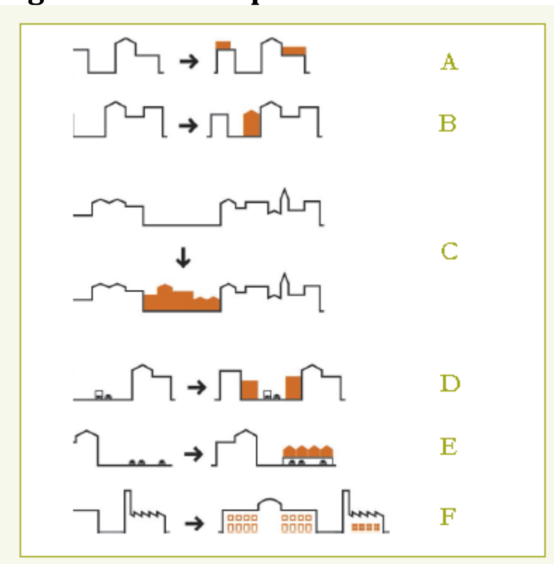


Figure 4.7. Concepts for densification in Eskilstuna



A = Allow vertical densification within certain limits as regards to access to parking and green space

B= Use of non-productive unbuilt land

C = Build between existing districts

D = Build-up oversized roads within 3 km from the centre

E = Use parking spaces which are not used fully

F = Transform certain industrial areas to mixed use with residential and commercial areas as well as work places

Figure 4.8. Possible areas of urban densification in Eskilstuna

Table 4.1. The potentials of different policy interventions in Eskilstuna to reduce road-based CO2 emissions

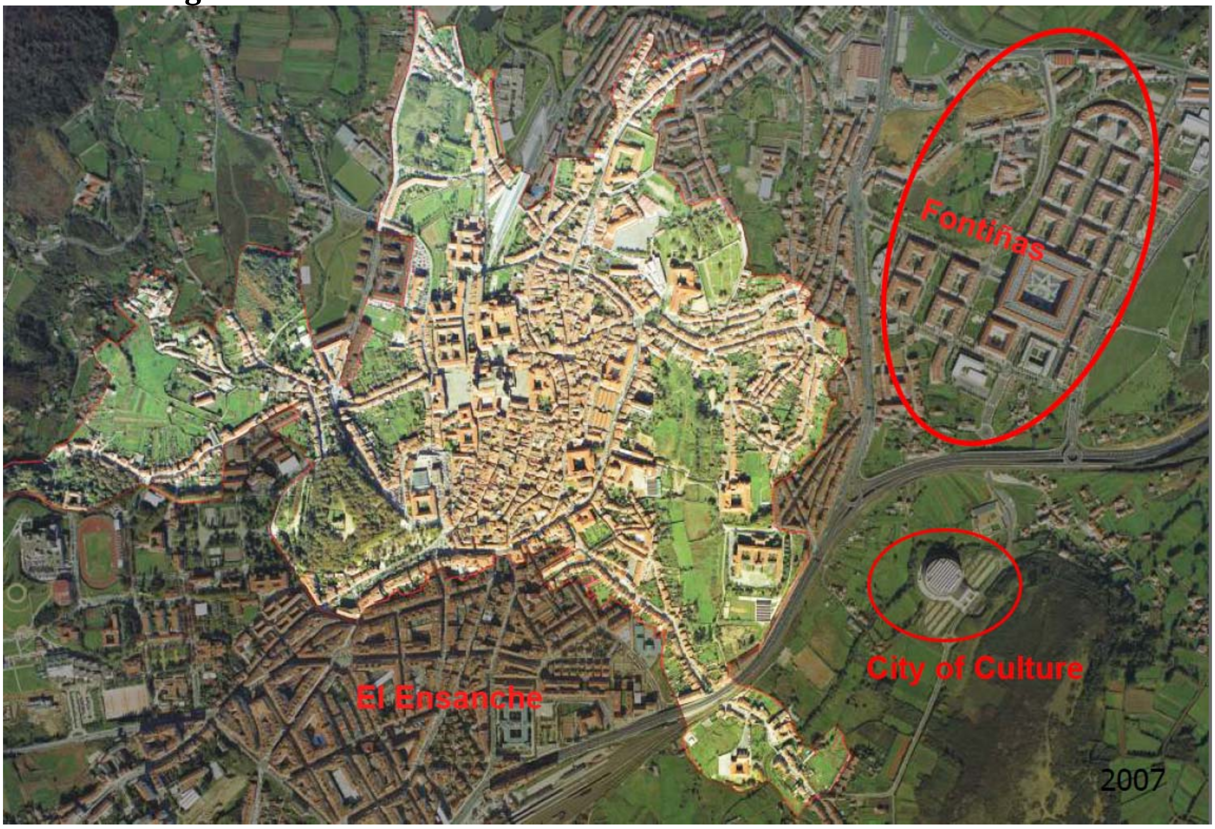
Year	Spatial planning	Regulations & economic incentives	Infrastructure and transport provision	Behaviour	Total effect on CO_2 emissions (1000kT CO_2)
2010	4%	67%	12%	17%	-5,0
2020	14%	50%	24%	13%	-9,4
2050	13%	33%	45%	8%	-19,8
Policy influence at the municipal level	large	small	small / medium	medium	

Source: Eskilstuna Kommun (2012).

In *Jyväskylä*, the role of spatial planning policy in addressing transport energy issues is not explicitly stated in the strategic plan for the city (Read & Hietaranta, 2015). However, the plan contains various objectives related to urban form which can potentially influence transport energy consumption. These objectives include compact urban development, co-location of jobs and residences, development along public transport routes, and concentration of development in existing urban centres. In order to make the city centre of Jyväskylä more attractive for cycling and less attractive for private cars (and to reduce their use), the city has introduced speed reduction measures which restrict speed within the city centre area to 20kph and 40kph in surrounding areas (Eltis, no date). These measures can help to reinforce spatial planning policies.

In *Santiago de Compostela*, as in Jyväskylä (above), the role of spatial planning policy in addressing transport energy issues is not explicitly stated (Fernandez Maldonado, 2015). However, the General Plan of Urban Development attempts to steer urban development that might promote transport energy efficiency: compact urban development within the existing urban fabric where possible. New development areas are identified in two types of area: (i) infill in existing urban areas; and (ii) high-density urban extension in the eastern part of the city in the Fontiñas neighbourhood (Figure 4.9). Despite its proximity to the urban centre, the Fontiñas neighbourhood is also located beside a motorway which potentially increases the propensity of residents to use the car.

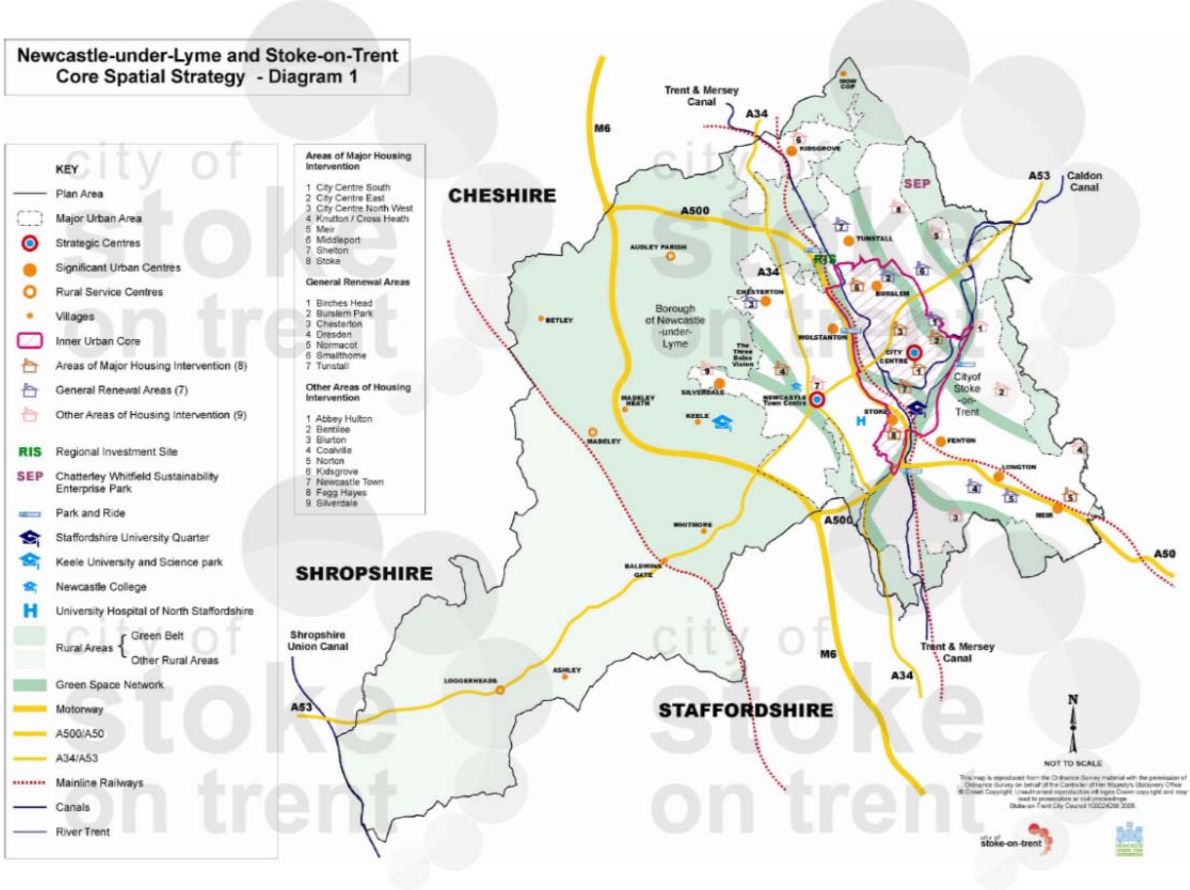
Figure 4.9. High-density urban extension in the eastern part of Santiago in the Fontiñas neighbourhood



In *Stoke-on-Trent,* the Core Spatial Strategy (for Newcastle-under-Lyme and Stoke-on-Trent) aims to '*minimise the adverse impacts of climate change in the move towards zero carbon growth through energy efficiency, promoting the use of renewable energy sources and green construction methods…*'. It identifies several policies that are relevant for reducing transport energy consumption. For example, the strategy stipulates that new housing will be primarily directed to sites within the inner urban cores, existing neighbourhoods especially urban renewal and housing intervention areas (Figure 4.10). The strategy also outlines that new development on previously developed land will be favoured, particularly where it can support sustainable patterns of development and provide access to services by foot, cycle and public transport (Rocco, 2015).

The transport plan for the city of *Tartu* directly refers to the relevance of urban form for transport demand, and seeks to promote compact multifunctional development in order to reduce the need for individuals to travel. However, contrary to the principle of compact and intensive development contained in the current Master Plan for Tartu, new low-density residential areas are mainly planned on the edge of the city. In practice, urban development in Tartu is currently characterized by urban sprawl due to factors such as the lack of cooperation between municipalities around Tartu (leading to dispersed urban development in surrounding municipalities), and competition between neighbouring municipalities for new development (Große, Groth, Fertner, Tamm, & Alev, 2015). At the national level, the Spatial Plan for Estonia emphasises the relevance of settlement structure, compactness of urban regions and multi-functionality as important preconditions of urban form for the efficient supply and use of energy.

Figure 4.10. Key spatial diagram from the Core Spatial Strategy for Newcastle-under-Lyme and Stoke-on-Trent



In *Turku*, urban intensification and densification is being pursued in the central areas of the city in order to limit urban sprawl and reduce the demand for transport. Planning policies seek to restrict decentralization and to promote new development in areas that are close to public transport routes (Mäkinen, 2014; Fertner et al 2015). A mixture of land-uses is promoted in order to decrease the need for mobility and to increase the local quality of life. In addition, infrastructure for more sustainable modes is being planned, although this is not yet well developed: there are currently only a few hundred metres of segregated cycle path in the whole city. While the city of Turku aims to limit urban sprawl and focus development in the central areas of the city, the fragmented municipal structure around Turku is currently thwarting this ambition. Neighbouring municipalities have other interests and do not share Turku's strategy of densification (Mäkinen, 2014). New developments (e.g. Skanssi) are situated close to a motorway exit, which potentially encourages the use of less sustainable modes of transport.

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4.5 Conclusions and recommendations

Urban form and transport energy consumption are inextricably linked. As a consequence, spatial planning is at the heart of the challenge to achieve more energy efficient cities. Spatial planning typically has long-term impacts. Nevertheless, spatial planning policy can have important effects on future travel patterns and transport energy consumption, especially in combination with other policies.

Both theory and empirical evidence suggest that more compact development (i.e. higher population and employment densities) can reduce transport energy consumption. Compact development can reduce travel distances and the need for motorised transport. Shorter travel distances can lower transport energy consumption by making walking and cycling more attractive alternatives to using the car. At the same time, higher densities help to increase the viability of public transit. The impacts of compact development can be enhanced when combined with other policy measures, such as mixing land uses to bring housing closer to jobs and shopping; designing street networks that provide good connectivity between destinations; and demand management measures, such as reducing the supply and increasing the cost of parking. According to a study by Bento et al (2005), a combination of measures like these is likely to result in a significant reduction of travel distance and transport energy consumption.

Summary of recommendations for spatial policy and practice

Larger settlements can be provide an opportunity for greater self-containment (although necessary settlement size – what is large enough - can vary between countries, depending e.g. on specific geographies) and a mix of uses offers access to a range of shops, services and employment within the urban area. This can reduce the need for travel. In order to promote more energy efficient transport use, the proportion of new development within or immediately adjacent to larger towns and cities should be maximised. Expansion of larger urban areas is generally preferable to putting development in smaller towns or dispersing development across a number of smaller settlements.

Strategic development location refers to the selection of areas for major new residential and non-residential development (employment, leisure and retail). To promote more sustainable energy efficient travel, the aim should be to locate development where travel generation is likely to be reduced, such as locations where there is good public transport accessibility, or close to existing centres. Development locations which may encourage long-distance journeys by car should be avoided (e.g. junctions of main roads/motorways).

Development patterns should be promoted which support public transport usage and discourage the use of the main road network for short, medium and long distance travel (e.g. commuting). Major new developments should be located near to public transport nodes where capacity exists or can be developed. Key public transport links and networks should be developed in urban areas, and development should be located adjacent to these links and networks.

The density of development should be high but consistent with local norms. Development densities should be in line with with liveability objectives and accommodation needs. Particular efforts should be made to maximise opportunities for high density development in areas adjacent to public transport nodes (e.g. within a 10-minute walk or an 800 metre radius).

Mixed-use development should be encouraged rather than mono-functional development. Key local facilities and services (e.g. local shops, schools) should be located within walking distance of homes in a neighbourhood in order to reduce travel distances. This will require a certain density of housing in order to generate sufficient demand for the shops and services to be economically viable.

Key services and facilities for the city or urban region (e.g. shopping centres, hospitals, libraries, educational institutions, leisure centres, cultural attractions) should be located within the existing urban fabric and should be very accessible by public transport. Cycling and walking routes should also be provided to these services and facilities.

A 'permeable' network of streets should be used to encourage walking, cycling and public transport use. Cycling, walking and public transport networks need to be safe, direct and attractive in order to maximise their popularity and use.

Table 4.2. Comparison between less energy efficient development ('sprawl') and more energy efficient development ('smart growth')

	Less energy efficient ('sprawl')	More energy efficient ('smart growth')
Density	▪ Lower-density, dispersed activities	▪ Higher-density, clustered activities
Growth pattern	▪ Urban periphery (greenfield) development	▪ Infill (brownfield) development
Land use mix	▪ Single use, segregated	▪ Mixed
Scale	▪ Large scale ▪ Larger blocks and wide roads ▪ Less detail	▪ Human scale ▪ Smaller blocks and roads ▪ Attention to detail
Services (shops, schools, parks, etc.)	▪ Regional, consolidated, larger scale ▪ High automobile access	▪ Local, distributed, smaller scale ▪ High pedestrian access
Transport	▪ Automobile-oriented transport and land use patterns, poorly suited for walking, cycling and public transport	▪ Multi-modal transport and land-use patterns that support walking, cycling and public transport
Connectivity	▪ Hierarchical road network with unconnected roads and walkways, and barriers to non-motorized travel	▪ Highly connected roads, and footpaths, allowing more direct journeys, especially by non-motorized modes
Street design	▪ Streets designed to maximize motor vehicle traffic volume and speed	▪ Streets that accommodate diverse modes and activities, with lower traffic speeds in urban areas
Public space	▪ Emphasis on the private realm (gardens, shopping malls, gated communities, private clubs)	▪ Emphasis on the public realm (streetscapes, pedestrian areas, public parks, public facilities)

Adapted from Litman (2014).

Maximum parking standards should be applied to new residential and commercial developments to reduce accessibility by car and lower the attractiveness of owning and using a car. Public transport access needs to be high in order to provide an alternative form of transport to car-based travel.

A range of urban form characteristics needs to be promoted by means of spatial planning policy in order to deliver more energy efficient urban transport. These characteristics are summarised in Table 4.2 which contrasts less energy efficient development ('sprawl') with more energy efficient development ('smart growth'). Spatial planning policies are just one of several types of policies (alongside pricing policies, education and awareness policies and other regulations) that have the potential to reduce the energy consumption of transport. These other measures are often complementary to spatial planning policies. Maximising the synergies between different policy instruments is an important consideration when developing spatial policies to reduce transport energy consumption.

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5 Urban energy generation (Niels Boje Groth, Christian Fertner, Juliane Große)

5.1 Introduction

This chapter focuses on the generation and distribution of energy in an urban context. Although a major part of energy consumption happens in cities, contemporary energy generation is less obvious connected to the urban structure. Energy consumed in transportation, based on fossil fuels, is produced at global scale; energy for electricity is usually distributed through a national or continental grid; energy for heating, if related to district heating systems or the use of local/regional resources for generation (e.g. biomass, waste), has a more local or at least regional character. In the latter, electricity might be a by-product of combined-heat-power plants, but still feeding into the national grid.

Furthermore, through the ongoing liberalisation of the energy market and a following change in the organisation structure of energy providers towards bigger co-operations as well as the development of new technologies as the 'smart grid'-solutions, local authorities in general seem to loose further influence on energy generation and distribution.

However, the focus on sustainable and efficient use of resources and energy at the local level, the mainstreaming of renewable energy production and ideas of urban energy harvesting put energy generation again on the local agenda. In this agenda the municipality act not only as a producer but also as an enabler, promoter and mediator towards the general public.

Furthermore, energy production (if renewable or not) has to happen somewhere, potentially also in the municipality, where consumption takes place. Therefore spatial conditions for different forms of energy production will also be highlighted here.

5.2 Energy generation and the city

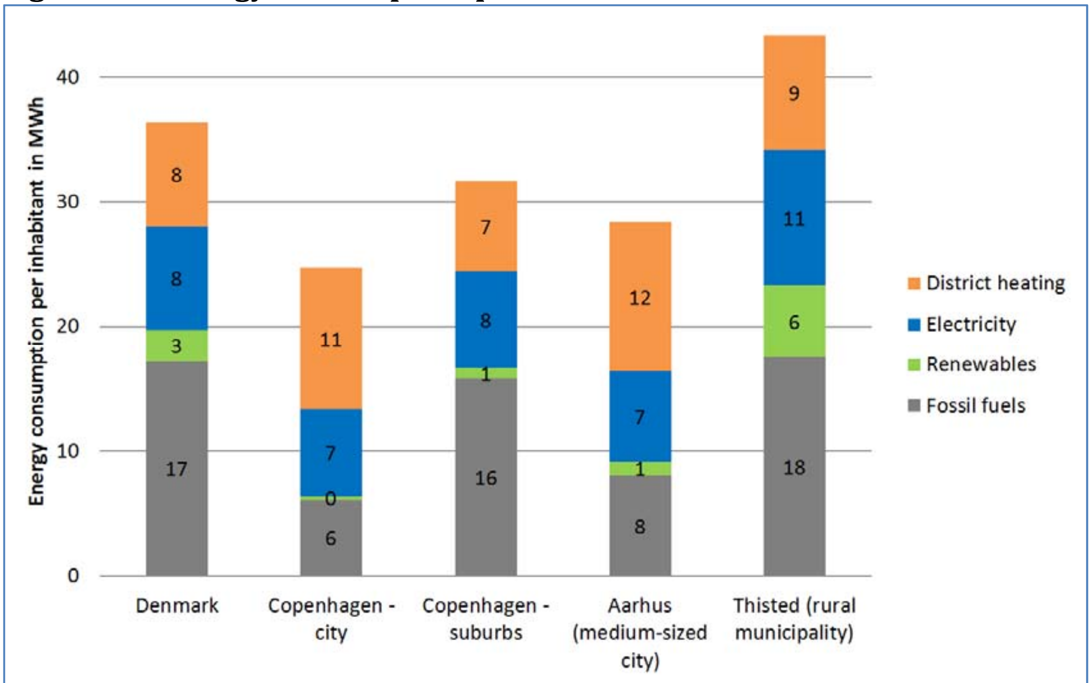
Urban energy generation is not new in our history. Available resources as water, biomass and building material were decisive for a city's survival. The depletion of those "may have become a constraint on the growth of cities" (Agudelo-Vera, Mels, Keesman, & Rijnaarts, 2011). However, since the industrial revolution and the exploitation of fossil fuels, cities gradually "became spatially disconnected from the sources that allow an urban life style" (Leduc & Van Kann, 2013). Today it is questionable if there is anything specifically urban about energy, as energy systems mainly function on national and international levels (Rutherford & Coutard, 2014), though with district energy systems as exception.

In this section we define urban energy generation as a result of two setups:

1. energy generation by the municipality (the municipality as producer) and
2. energy generation in the municipality, promoted by the municipality via (spatial) planning (the municipality as a promoter/enabler, possibly also limiting factor)

The point of departure should be the energy which is consumed in the city, rather than where the energy actually comes from. The energy consumed is usually the driving force (at least for the local authority) to engage in energy generation. Consumption patterns can though be very different as Figure 5.1 shows by the example of Denmark, where there can be big difference between energy consumption patterns in urban, suburban and rural areas – in absolute but also in relative terms. While in suburban and rural areas it is the consumption of fossil fuels mainly for transportation which are most prominent, in urban areas distict heating might play a bigger role in the overall energy consumption. Also, local authorities often have an important role to play in the distribution of the energy, e.g. by creating a district heating network or managing the local electricity infrastructure.

Figure 5.1: Energy consumption per inhabitant in MWh, 2012



(Region Syddanmark & Statistics Denmark, 2014)

5.3 Visions for the city's energy supply

Many cities today have energy production somehow included in their local strategies – directly or indirectly. A couple of ideas and brands around that have emerged, including

- A productive city
- A self-sufficient and independent city / a resilient city
- A regenerative city (Girardet, 2015), producing energy, recycling and reusing
- A CO2-neutral city (zero-city)
- Cities with a cicular (inclusive) metabolism

Figure 5.2: Linear and circular urban metabolism (Leduc & Van Kann, 2013)

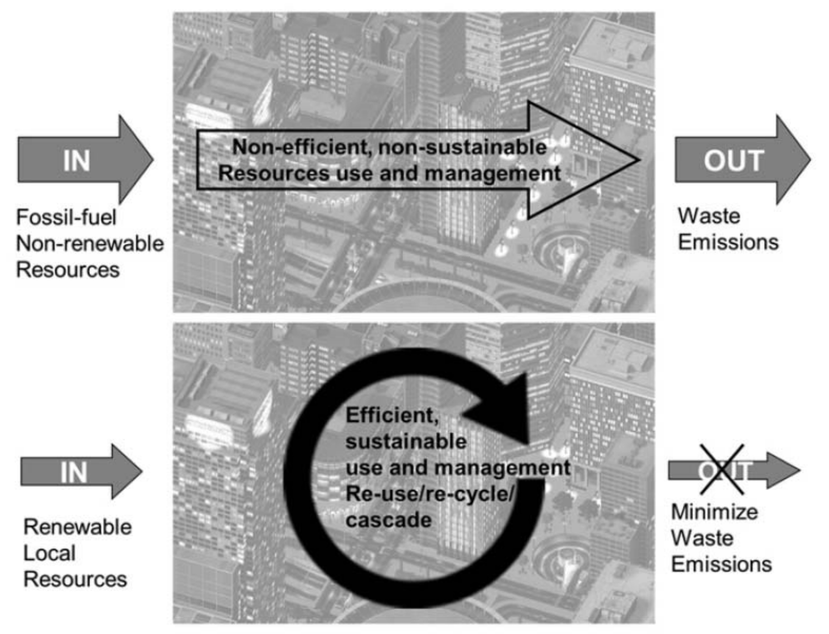


Fig. 1. Urban resources use and management; linear – resource-to-waste – metabolism vs. circular metabolism (based on Girardet (2008)).

These concepts are usually also related to the more general idea of a sustainable city. It is however doubtful if a city really can be sustainable in the meaning of self-sufficient, i.e. only dependent on its own resources. *"Some studies advocate that to consider a city sustainable, it must be self-sufficient in terms of energy, materials, food and water ... These authors express the importance of increasing the self-sufficiency of cities because this property boosts the efficiency and sustainability in resources usage, increasing the autonomy and economic resilience against the negative effects of the global economic crisis [...] Despite this, among some authors there is some criticism about the concept of self-sufficient cities [...] They assert that sustainability is a desirable and attainable goal at the global scale, but do not agree that is achievable locally."* (Barbosa, Braganca, & Mateus, 2014). Still, self-sufficiency (especially after a transition towards renewable energy sources) can be a realistic vision at a regional level.

The general idea of a self-sufficient city can result in cities (or urban regions) not only consuming resources but also producing them by harvesting available local renewable resources and wastes (Leduc & Van Kann, 2013). But besides the ambition of a renewable energy supply, also the aim of being independent from imported energy is fueling the idea of self-sufficiency. In Estonia, the independency from foreign energy supply plays an important role for policy making and is also one of the reasons for the extensive use of oil shales for electricity production, covering almost all domestic demand (Rudi, 2010). Although this contributes to Estonia's temporary self-sufficiency (based on limited, non-renewable sources), it is a very polluting and environmentally-harming way of energy generation. In that sense, the aim for self-sufficiency is in opposition to climate goals.

But the PLEEC cities show also that the ambition of providing sustainable energy in their municipality does not necessarily mean to invest in renewable energy generation inside the municipality. For example the local energy supply company in Eskilstuna (EEM) has invested in solar cells and wind turbines in other areas in Sweden to increase the share of renewable energy in their portfolio (Groth, Große, & Fertner, 2015). However, the precondition for that is a reliable grid and distribution system; something which cities can hardly influence by themselves.

5.4 Energy supply across spatial scales: National grid, regional hinterland, city and small scale solutions

The production of energy in cities (local production) is rather complex, formed as it is by diverse ownerships and new technologies and related to diverse spatial scales. Further, the frame conditions for local energy production are changing, by energy policies, technologies and markets. Therefore, what belongs to the city-level of energy production should not be taken for granted.

The energy systems today have developed to a degree of complexity that compete withs any mechanistic models with simple relations between consumer and producer. In order to deal with complex feed-back relations and contradictory impacts of policies systems theory is often used (Lund et al., 2010; Magnusson, 2012; Ubach et al., 2014). Facing the complex energy systems, we need to clarify how local energy production and the local energy producer can be singled out in the myriad of relations. Energy plants that physically are located in the local might produce for the national grid; and decision makers situated in the local milieu might not be independent actors. Rather, some are members of large ex-local systems. Thus, local house owners, private housing estates, cooperative housing societies, local energy companies, energy processing industries and municipalities, as independent actors, make their decision on energy investments based on individual priorities on economic profitability and climate responsibility, whereas they, as members of large ex-local energy systems, are subject to optimization of regional or national systems for storage of energy or timely production of energy during periods of changing supply-demand.

In what follows, we shall try to define what local energy production is in institutional and technical environments of complex interdependencies.

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5.4.1 Energy production in four phases

Four phases in the development of the current energy system (with focus on heating and electricity) highlight the development from independency towards interdependency.

Local generation

Historically, the energy demands of cities where covered by local generation. Since the industrial revolution increasingly fuels were imported (wood, coal) and transformed into heat and electricity in local plants. While oil production became a global business (though with increasing focus on providing energy for transportation), nation-wide electricity grids were evolving since the 1920s and 1930s, in the beginning still facing many different local and regional configurations. Gas got first wider in use in the 1960s and 1970s. Power production was therefore for a long period after the WWII still a local or regional business and. In countries as Denmark, Sweden or the Balitc countries, local energy production was reinforced by the installation of local district heading plants in the 1950s and 1960s. In these countries, the construction of local district heating was connected closely with the post-war housing programmes. District heating was characterised by simple relations between local consumers and local producers connected by local heat grids. Thus, the energy companies owned all elements of the energy value chain, from production to the distribution of energy to the final consumers. Electric power and district heating was 'broadcast' from central units to the individual customers.

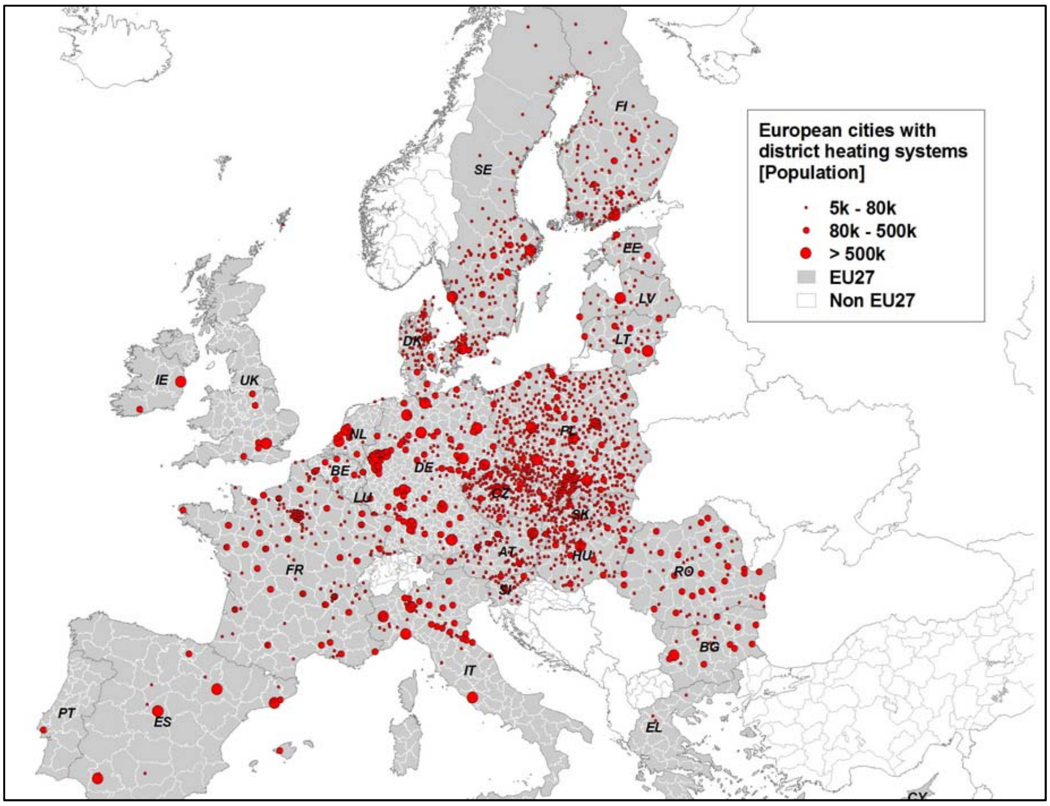

Figure 5.3: European cities with district heating, location and size of cities. The map reveals substantial differences between North Eastern Europe on the one hand and UK and southern Europe on the other. The project Heat Road Map 2050 recommends district heating to be increase from current 10% on average in European cities to approximately 50% in 2050 suppied with heat pumps in village and scattered build-up areas. Source: Heat Road Map Europe 2050, Connoly, D. et al. (2013).

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Cogeneration
The oil crises in the 1970s called for energy savings to reduce the vulnerability that was created by the dependency on fossil fuels. One of the policy implications was the decision to encourage the development of a more efficient use of energy, notably the combined district heating and power plants (CHP). The combination of heat and power generation was a first step into the new complexity of interdependencies between different kinds of energy production as well as multilevel connections of energy companies, since the CHPs were connected, on one hand, with the local heat grid and, and on the other hand, with a local electric grid that was further connected with the national grid.

Liberalisation
In 1996 the EU launched the electricity market directive (European Commission, 1996) aiming at the liberalisation of electricity production. Two years later, the electricity directive was followed by a corresponding directive on the liberalisation of the gas market. The principle used for introducing competition in the electricity and gas supply industries was that generation and supply are subject to competition, whereas the grid activities – transmission and distribution – remained natural monopolies subject to regulation.

The cogeneration of district heating (DH) and electricity requested a homogenisation of two principles of price calculation, the price of heat from DH plants, based upon the principle of cost-recovery of each single DH, and the price of electricity based on the market. A homogenisation of the two price principles was needed in order to avoid cross subsidies between heat and electricity sales – and the market principle was chosen as the common principle (Grohnheit & Mortensen, 2003). As a consequence, neither consumers nor distributers were no longer tied to own power plants, thus, the liberalisation implied that the power plants no longer should be anchored in the local community; and nor should they hold monopolies within certain geographical areas. From now on, they should compete for the customers and about the prices – not only at the local and national levels, but all the way up to the European level (Frederiksen, 2012).

To be a player at the liberalised market is more demanding than holding a monopoly at the local market. Liberalisation therefore was followed by several mergers of local energy companies, mergers of municipal plants with those of larger municipalities as well as take overs by large private companies. As a result, energy companies tended to become fewer and larger and with ownerships that tended to loosen the ties with the local. If this leads to sustainability is questionable, as responsibilities and awareness decrease in the globalised market. Efficiency gains in a global setting might not necessarily reduce demand (as e.g. would be stated in a strategy of a specific entity), but rather increase it because of its availability.

Climate policy and smart grid
The introduction of climate policies in energy production called for further cooperation in the sector. According to (Frías et al., 2009 , 445) the public goal of a sustainable electricity system is strived for in European member states, through a number of national technology-specific support schemes in the member states ”for renewable-based electricity generation (RES-E) and co-generation of electricity and heat (CHP). This objective is a main driver of the growth of distributed generation (DG) – generators connected to the distribution network – to significant levels.”

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Table 5.1: Categorisation of sustainable electricity supply technologies

	Combined heat and power (CHP)	Renewable energy sources (RES)
Large-scale integration	Large district heating (>50MV) Large industrial CHP (>50MV)	Large hydro (>10MW) Off-shore wind Co-firing biomass in coal power plants Geothermal energy
Medium and small-scale generation	Medium district heating Medium industrial CHP Commercial CHP Micro CHP	Medium and small hydro On-shore wind Tidal energy Biomass and waste Incineration and gasification Solar energy (PV)

Source: Frías et al., 2009, 446

In the climate based energy policy, substitution of fossil fuels by renewable resources (RES) became a key issue. Since RES, e.g. wind and sun, are not steadily available, a focus on availability of resource supply became urgent, e.g. by timely substitution of one non-available resource by another available resource. Further, storage of energy produced by available resources in periods of low demands became urgent. These challenges call for cooperation between different kinds of energy production and storage capacities.

These diverse needs lead to the development of the so-called 'smart-grid', i.e. systemic monitoring of several production units to find optima in a world of fluctuation of prices, energy resources and energy demand. Smart grid solutions have pronounced impact on the energy system. It is not just a system for optimisation of existing production. Also, it is about development of systems best suited for optimisation. (ForskEL et al., 2014).

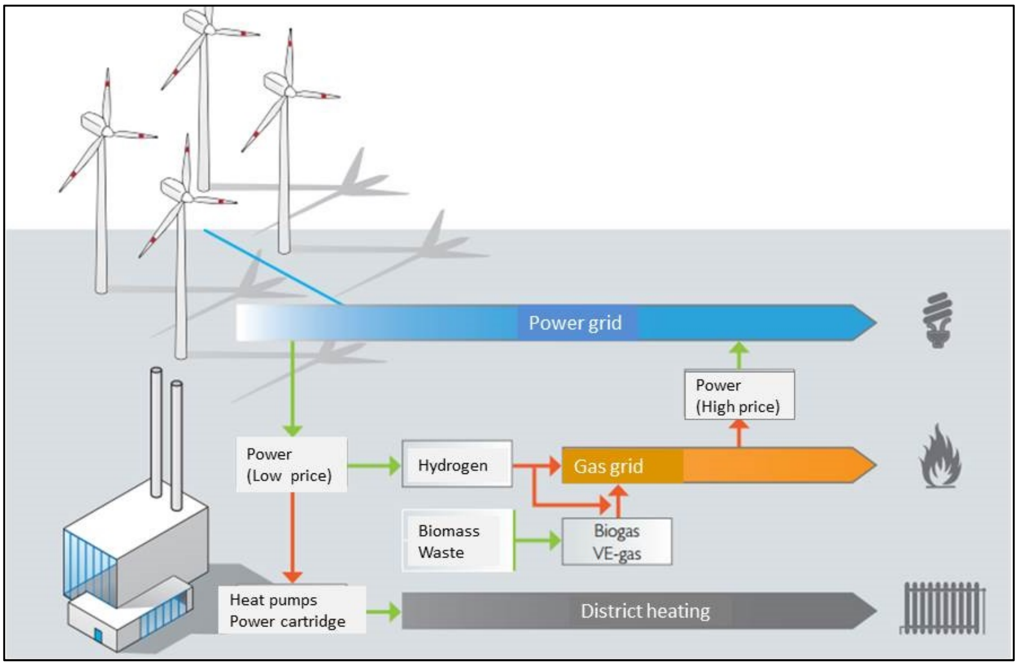

Figure 5.4: In the future, power is no longer just 'broadcasted' from producers to consumers. Several producers cooperate on filling the gabs in silent weather (power from gas) and to storage power when the wind blows (e.g. producing hydrogen and supplying district heating by power driven heat pumps and cartridges). Source: Klima-, Energi- og Bygningsministeriet (2013)

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“Smart Grid may be characterised as an upgrade of 20th century power grids, which generally "broadcast" power from a few central generation nodes to a large number of users. Smart Grid will instead be capable of routing power in more optimal ways to respond to a wide range of conditions and to charge a premium to those that use energy during peak hours.” (Gulich, 2010 , p. 9).

In the smart grid, there is a need for competent operators. This is the background for the formation of so-called ‘aggregators’ who, in the interest of small producers or consumers, acts on the electricity market. One such example is the Danish NESA Energy, representing about 200 power producers, many of which are CHP companies. Each of the partners is equipped with remote control units facilitating a central coordination and optimisation of the partners 500 generating units by NEAS. “The CHP plants plan their day-ahead production considering both the electricity market and the district heating system. Over the course of the day they deliver different balancing services. They remove capacity, when there is a surplus. They offer NESA storage in hot water accumulation tanks and the district heating system. This storage facility has been further encouraged in district heating systems, allowing the district heating plant to maintain high levels of efficiency wile decoupling their electricity and heat generation over certain time periods.” (COGEN Europe, 2014)

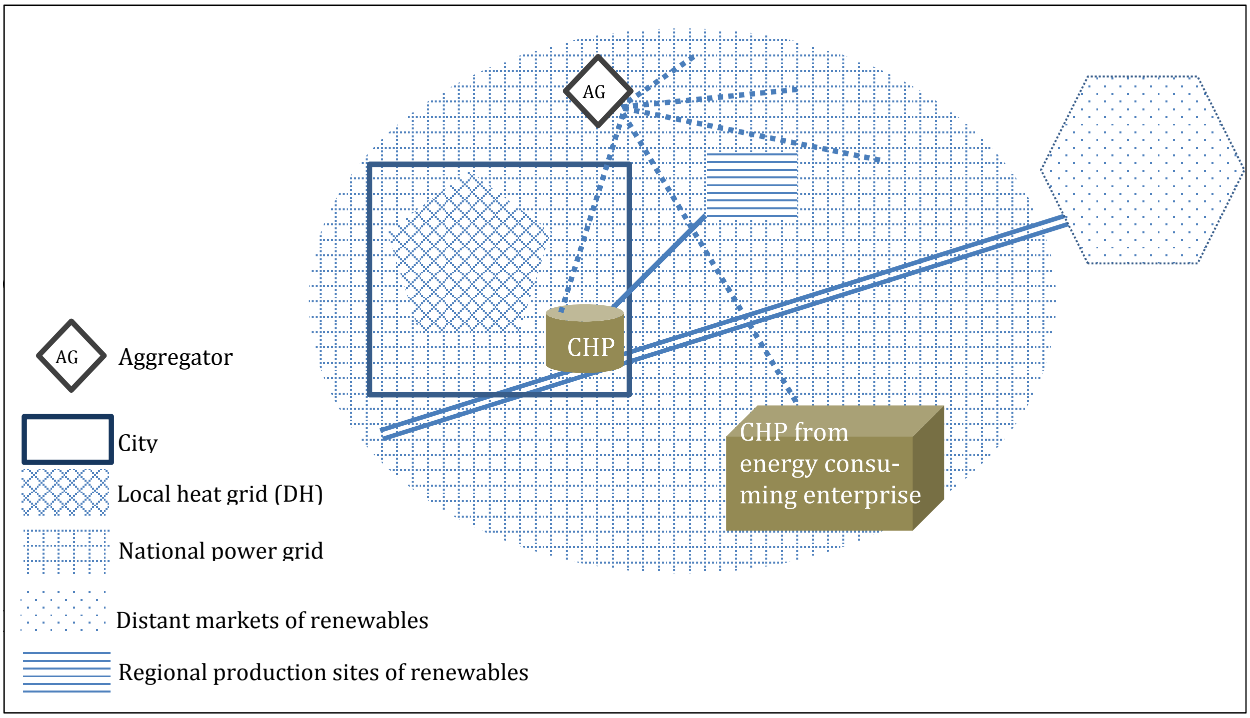

Figure 5.5: Energy space(s): Relations of a local CHP plant - with renewable resource suppliers, local heat grid, national (/international) power grid and a national aggregator taking responsibility of monitoring and optimisation of production.

The work of the aggregator illustrates the key issue of smart grid, remote monitoring of energy generation in the interest of the total system. As a consequence, the individual producer, including the local energy producer, sacrifices his autonomy for the benefits of being part of the ‘common good’. If sustainability is a goal, the aggregator thereby also has the key role of managing the ‘common good’ by e.g. favouring renewable energy in the system.

If the development of climate and energy policy will go on in the years to come, the system approach, as represented by the smart grid, will expand and be the mediator of energy production and consume. Hence, it shall be within this context, that local energy strategies shall be defined. It is likely that local energy policy will turn into fulfilling obligations as defined by the larger system, rather than develop independently. This does however not mean that municipalities, cities or regions cannot advocate for their say in the system, by definining its rules.

In some instances conflicts between local and national energy policies may arise. As an example; in supplying buildings with heat and warm water, local energy policies are faced with two alternatives: on the one hand the promotion of energy saving in buildings by insulation and, on the other hand, promotion of RES based district heating systems.

> *One view states that future low-energy buildings could completely remove the need for heating or even, by the use of e.g. solar thermal energy, be plus energy house producing more heat than they demand. The other view states that excess heat production from industries, waste incineration and power stations may also be used together with geothermal energy, large scale solar thermal energy and large-scale heat pumps to utilise excess wind energy for house heating. In the first case, a district heating network may not be needed, while, in the latter case, a district heating network becomes essentiall. (Lund et al., 2010)*

In the perspective of technical achievement of new housing districts, the first choise based on energy efficient buildings and no district heating is attempting. But in the broader perspective of the community, district heating combined with heat pumps in sparsely built up areas is essential, rather than obsolete. The advantages of district heating include the ability to help utilizing heat production from waste incineration and industrial excess heat production as well as integration of geothermal heating, biogas production and solid biomass such as straw. (ibid)

Figure shows how the local CHP is connected with a regional and international supplier of RES via the national and regional infrastructure. Inside the borders of the municipality the CHP is connected with local heat grid. Due to the production of electricity the CHP has chosen to be a member of an aggregator, made responsible for the optimal production of power. Also, industrial CHPs are connected to the Aggregator. While the heat is produced for the local heat grid, the electricity is distributed by the aggregator to the national (/international) power grid.

5.4.2 Consumption – production – transmission – distribution - regulation – calibration.

The basic types of activities in world of energy production may be summarised by the activities mentioned in the above heading: In modern energy production, former simple relations between *consumption* and *production* are now connected by an independent *transmission* and *distribution* allowing for competition between consumer and producer. An important driver is EU and national *regulations* of frame conditions for energy production, distribution and consumption. The growing number of interdependencies has caused the need for *calibration* of the activities by e.g. aggregators and smart grids.

5.4.3 The local energy policy

The lessons from this brief overview are that local energy policies are embedded in larger energy policies. Local policies have to respond to the needs of the larger policies that demands cross cutting calibration of supply and demand as represented by the smart grid. On the other hand, these give also new possibilities for cities and regions as e.g. the case of Eskilstuna's investment in renewable energy outside their territoriy shows. Under these circumstances we shall suggest that production of energy is local if produced locally for local consumption:

1) in private households by the owner of the household (e.g. solar panels, solar cells, heat pumps) or
2) in a local energy plant distributing energy via the local heat grid - no matter the ownership of the producer (e.g. district heating).

Cogeneration of electricity from local heat production, contributing to national consume via the national power grid, is a by-product contributing to the effiency of the heat production and, hence not local electricity production.

5.5 Local production

The raison d'etre of local energy production is space and proximity. Space is needed for solar panels, solar cells and heat pumps and proximity are needed for efficient transportation of heat. Other kinds of energy production, such as the production of electricity, is relatively independent of distance when produced in central power plants and transported in high voltages transmission grids – however, cities producing electricity still have the benefit of that. Electricity production by wind turbines and water turbines are of course determined by optional sites for wind and hydropower, respectively. Besides the technical requirements, strategic and political requirements are greatly influencing how central and local energy production is combined. Thus, the strategic turn towards combined production of heat and electricity and vice versa, is decisive for producing electricity were heat is produced, e.g. production of electricity at district heating plants. Also, it is decisive for production of heat in power consuming plants, such as metal works. Finally, local production may be chosen to enhance security of energy production, to develop energy technology as a local competence and job generator or simply due to political preferences for local influence.

As emphasised in the previous section, the trend towards building large complex energy systems is not about replacing local with central energy production. Rather, it is about combining local and central production and monitoring of future energy systems, in which local production has a big say.

In table 3 an overview of different kinds of local production is shown, emphasising whether the production is individually organised by the single household or organised collectively by e.g. the municipality or an energy company on behalf of several households.

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5.5.1 District heating and CHP

District heating is a major contributor to local energy production, especially in the Nordic and Baltic Countries. In all the case cities district heating is combined with electricity production in combined CHP plants, most of which are fuelled by bio mass.

In Turku district heating is generated at the CHP plant in Naantali. Heat is generated using a variety of fuels: coal, refinery gas, waste, wood, biogas and oil. The combined heat and power production cuts fuel consumption by one-third (Community Structure 2035, 136). In 2010 the waste incineration at the plant stopped. There will be changes in the energy generation solutions in the region when the Naantali power plant in 2017 is replaced by a new multi-fuel power plant. The aim is to use domestic biofuel as much as possible. (*Turun Sanomat* 10 February 2014.)

Table 5.2:Types of local energy production - Information on individual stoves and furnaces, as well as furnaces for central heating in housing estates is not included.

	Individual	Collective / Municipal	Eskilstuna	Tartu	Jyväskylä	Turku	Stoke	Santiago
Stove	X							
Central heating in housing estates		X						
District heating (DH/CHP)		X	X	X	X	X	X[1]	
District cooling		X	X[3]	X[1]		X		
Shallow geothermal – ground source heat pumps	X	X		X	X			
Deep geothermal energy		X					X[1]	
Solar energy	Roof Panels	Solar farms	X	X	X	X	X	X
Wind		X	X					
Biogas from waste		X	X		X	X		
Waste incineration		X				X[2]		
Potential • Micro CHP • 'Surface energy' e.g. Bicycle lanes • Excess heat from industry		 X X X						

[1] implementation decided
[2] closed down in 2010
[3] Smaller district cooling grids for industries

The CHP plant in Tartu is fuelled by peat extracted from large inland areas with peat. Although peat is biological, it is not considered renewable. The peat excavation areas are owned by Fortum Tartu (Figure 5.6).

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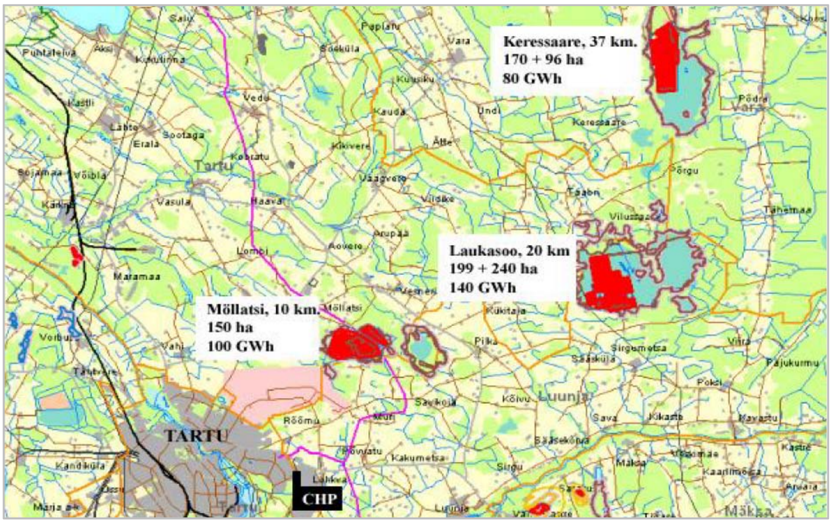

Figure 5.6: CHP plant and peat excavation areas of Fortum Tartu (Presentation Fortum Tartu, 06.06.2014)

Stoke-on-Trent has decided to start up what is going to be England's first district heating plant. It is going to be fuelled by deep geothermal energy from natural resources about 2 kilometres below the city. Due to the lack of central heating in Stoke-on-Trent, the project is only for a new housing area.

The use of bio fuels augments daily hauls with biomass to the CHP plant, many of which still is located close to the centre for cities, as e.g. in Estonia. A relocation of the plant is currently being considered in order to respond to two challenges: the need for a technical renewal of the 14-year-old plant and the need to reduce the heavy transport of wood chips into the city. The new CHP is planned to be located 10 km east of the city in a new logistical park situated between the Svealand Railway and the E20 motorway, see figure 8.

Currently, the Eskilstuna CHP consumes 900,000 MWh biofuels (wood chips) per year, delivered by 8,182 lorries per year. In the cold winters, about 80 lorries pass through the town each day. Former plans included a new combined heating and power plant which would decrease the annual number of transports to the city to about 3,500 lorries, while 30- 50% of the wood chips will be delivered by rail to the new plant, thus reducing the number of lorries by 2,800-4,600. However, the plans are currently (June 2015) halted.

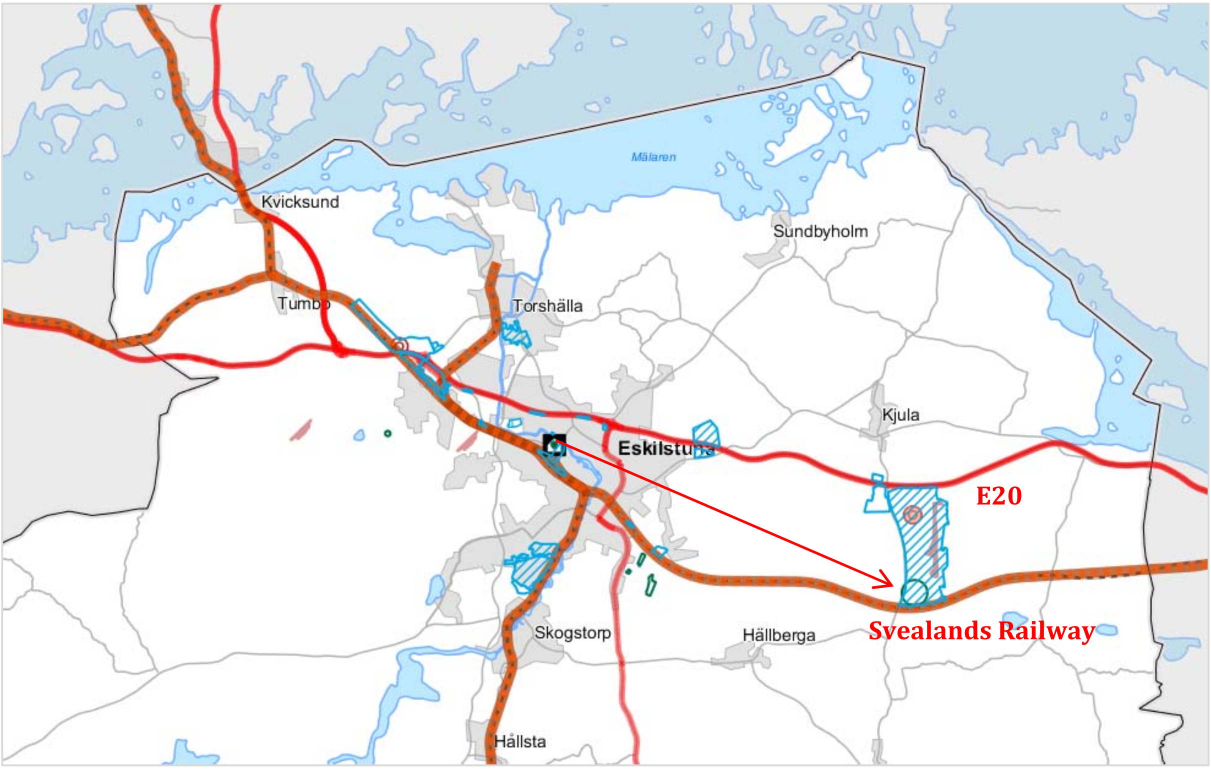

Figure 5.7: Relocation plans of Eskilstuna CHP – from urban to logistic position.

In Figure 5.8 an overview of district heating in a number of countries is given. Two statistics are combined. The blue columns reveal the share of CHP in the national electricity production, whereas the red columns show the percentages of citizens serviced by DH. Data were though not available for all countries.

As revealed by Figure 5.8, the use of DH varies substantially in the EU (see also figure 4), and so does the contribution from CHP to national electricity production. Usually, CHP is driven by residential consumption of heat. But in the Netherlands, with high consumption of heat in the green houses and refineries, industrial heat processes have been the drivers for installing combined power production. Thus, two different kinds of CHP seems to be at play, the residential and the industrial CHP, driven by heat for residential purposes and heat from industrial processes, respectively.

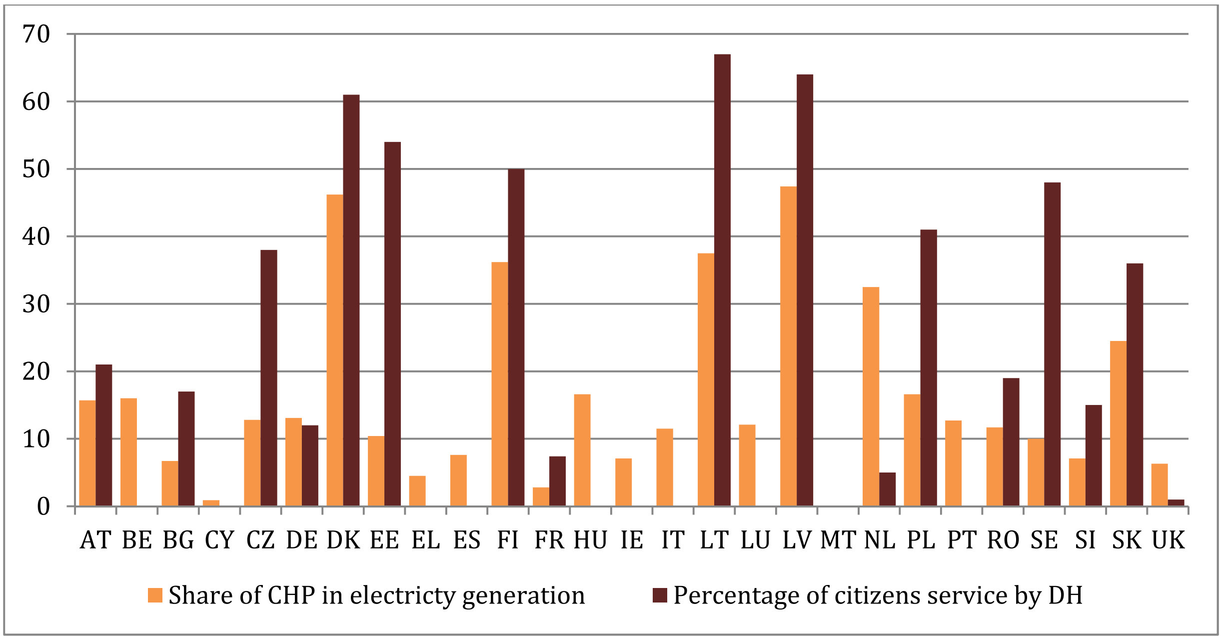

Figure 5.8: The use of combined heat and power (CHP) and district heating (DH) in the EU member states.

Figures from two statistics are here jointly presented. Unfortunately, not all figures were available in the DH statistics (CY, EL, ES, HU, IE, IT, LU, PT). The figure reveals two distinct types: residential and industrial CHP. Residential CHP was driven by DH supplemented by power production. Prime examples are DK, FI, LT, LV, SK showing high DH production combined with high shares of electricity produced by CHP. Also CZ, EE, PL, SE need mentioning due to large production of DH, however accompanied by lower shares of electricity production. Industrial CHP is first and foremost represented by NL, showing a large production of CHP power combined with only a minor production of DH. Industrial CHP is driven by heat from industrial processes (NL: green houses and refineries) supplemented by additional power production. DE and UK resembles, at much lower rates however some of the industrial CHP profile also. Source: Percentages of citizens serviced by DH, Euro Heat and Power (http://euroheat.org/Statistics-69.aspx). Share of CHP in electricity generation, EU Energy in Figures, p. 95: (http://ec.europa.eu/energy/publications/doc/2013_pocketbook.pdf).

Denmark and Latvia show high figures on DH and CHP as well, whereas Sweden and Estonia shows high rates of DH but modest shares of CHP, indicating potentials for further transformation of DH into CHP. The industrial profile of CHP production in the Netherlands seems to characterise, however at a more modest level, the profiles of the UK and Germany. As revealed by figure 5.9, excess heat activities are available all over Europe. Only about 3% is used for district heating. Thus, the potentials for profiting upon existing excess energy production is potentially available for district heating.

As for example in 1996, following from a governmental directive, Frederikssund district heating plant was transformed into a combined heating and power plant based upon natural gas. To day, Frederikssund district heating profits from cooperation with a local company, Haldor Topsøe, an international renowned producer of catalysts. To day approximetly 45% of the heat distributed from the distric heating system is excess heat from the company. A further input is expected in the future.

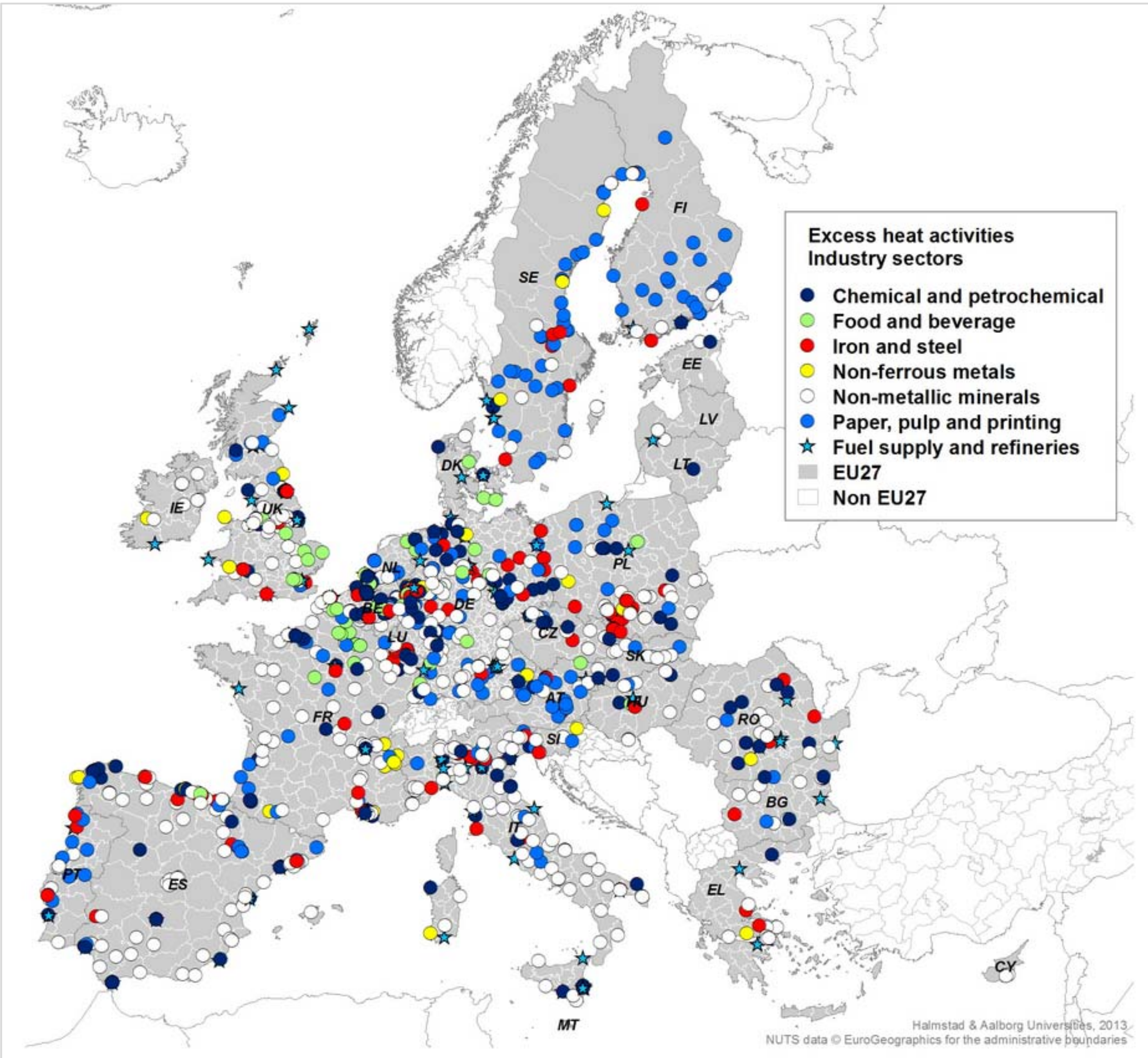

Figure 5.9: Excess heat activities in industrial sectors. Source: Heat Road Map Europe 2050, Connoly, D. et al. (2013).

5.5.2 District cooling

District cooling has been introduced as an energy efficient alternative to traditional powerbased cooling systems. In Tartu, a district cooling system based upon water from the Emajõgi River is going to start up operating in 2015. The major customers of the new system are situated in down town Tartu, characterised by high building density and business and shopping centres.

In Turku, a district cooling system was inaugurated in 2000 (Fertner, Christensen, Große, Groth, & Hietaranta, 2015). Further, in 2009 an extraction of heat energy from household waste water by a heat pump was set in operation. The heat recovery takes place after the treatment process and before the water is discharged back into the sea. Prior to discharging the cooled water into the sea, it is used a second time to cool the water for Turku's district cooling network. The heat pump plant replaces district heat for about 12,000 Turku residents, without any local emissions to the air and the electricity required to run it is mainly produced without carbon dioxide (Merisaari & Keski-Oja, 2009).

5.5.3 Geothermal energy

As mentioned above, Stoke-on-Trent has decided to make use of deep thermal energy sources in a new district heating system. Stoke-on-Trent profits on natural sources of energy situated below the city, which is not generally optional. However, shallow geothermal energy is more generally available for extraction by heat pumps. Thus, most case cities include shallow heat pumps in their energy strategy. Especially cities with high production of district heating in urban areas rely on individual heat pumps in sparsely built up areas outside the city.

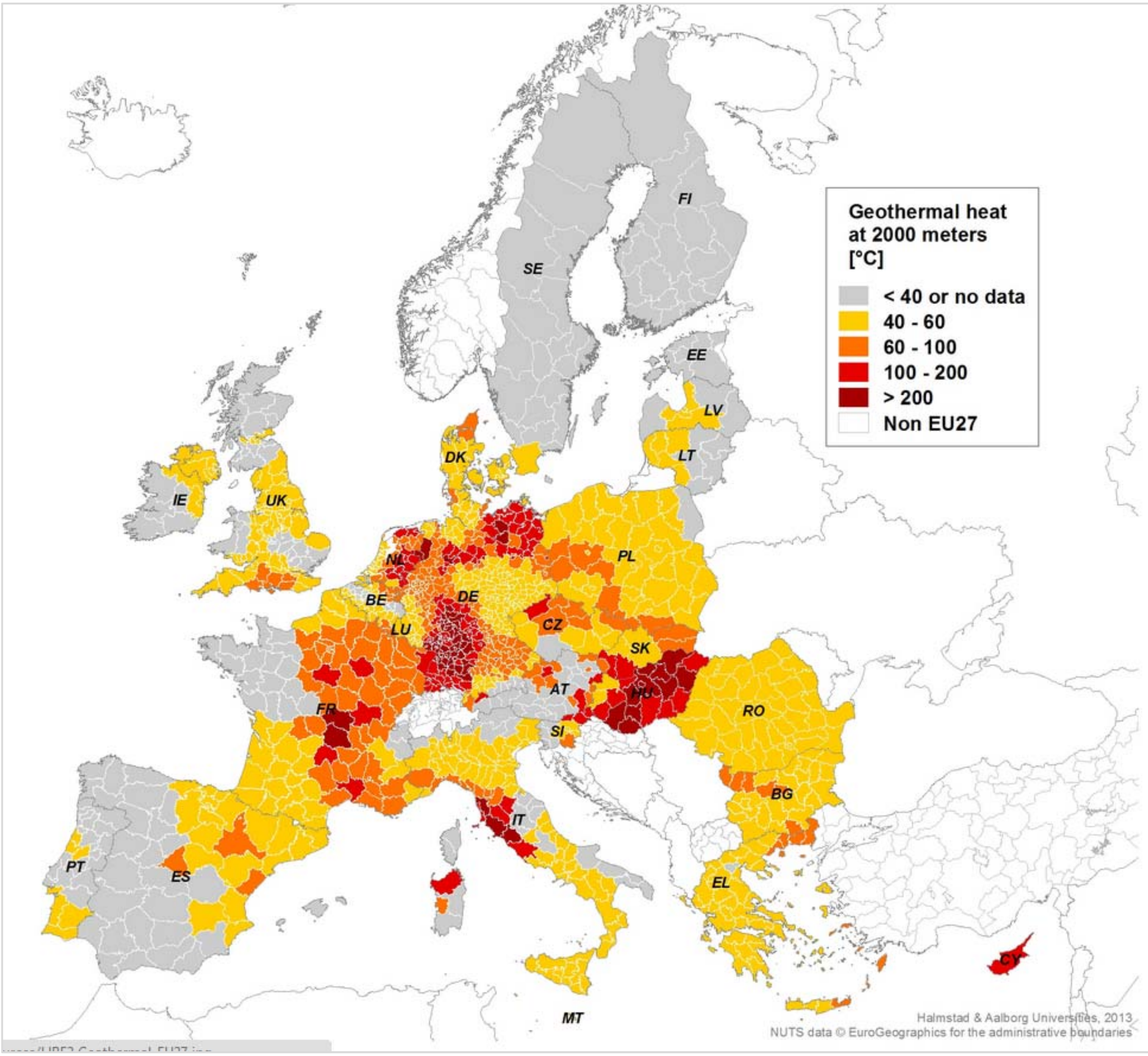

Figure 5.10: Geothermal heat at 2000 meters. Source: Heat Road Map Europe 2050, Connoly, D. et al. (2013).

If combined with other systems, such as solar cells, heat pumps are, however, also relevant in new urban areas. Such an example is being developed in a new projected town, Vinge, in the greater Copenhagen region. Due to high insulation and low temperature heat systems (floor heating), the houses are suited for solar and geothermal energy and less attractive for district heating, especially during the construction phase. A feasibility study comparing a decentralised individual system, a semi-decentralised system and a centralised system (district heating), gives a priority to the semi-decentralised system,

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based on heat pumps constructed for small clusters of houses, rather than individual heat pumps. If, in the future, a district heating system shows to be a better alternative, it would be feasible to connect with the clusters (Rambøl *et al.*, 2013).

5.5.4 Solar energy

Solar energy includes power cells and heat panels. These devises are mushrooming on the roofs of individual households, and – like heat pumps - seen as a complement to district heating.

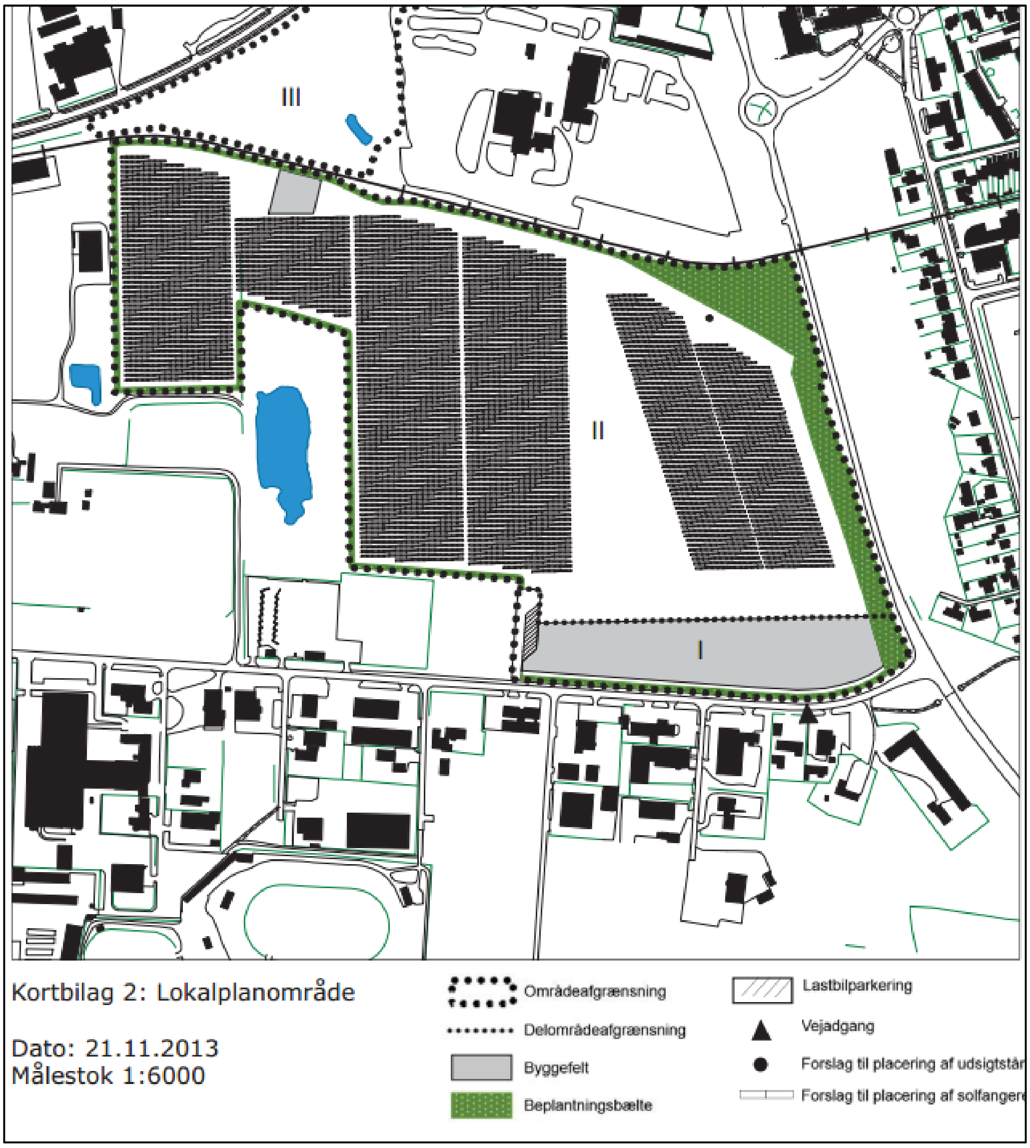

Figure 5.11: Local plan for Vojens District Heating plant. Area 'I', the district heating plant. area 'II' the solar panels, area 'III' the warm water reservoir. The whole area is sistuated in an industrial area of the tow.

Like heat pumps, solar cells and panels are also relevant in larger scales. As an example, one of the world's largest reservoirs for warm water heated by solar panels has been established in the Danish town Vojens. The reservoir is for 200 million litre warm water, heated by 4.166 solar panels with a joint surface of 52,500 m2. The reservoir was established in a former gravel pit. The solar panels are added to 17,500 m2 panels already

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established, bringing the total surface up to 70.000 m2. The system is going to service 2.000 households in the city (Bindslev, 2014).

5.5.5 Wind and hydropower

Wind and hydropower are tightly anchored at sites suitable for wind and water turbines. Also, they are costly. Therefore, municipalities enter into wind and hydro production only as shareholders or in cooperation with other municipalities. In Turku, the share of wind power will increase to 10% in 2020. In 1998 the Hyötytuuli wind power production company was founded. It was founded by several major Finnish energy companies, including Turku Energia. In 2003, Turku Energia and two other energy companies bought "Eastern Norge Svartisen", a Norwegian hydro power plant. Also, Eskilstuna Environment & Energy (EEM) has invested in solar cells, hydro and wind turbines, however only minor shares.

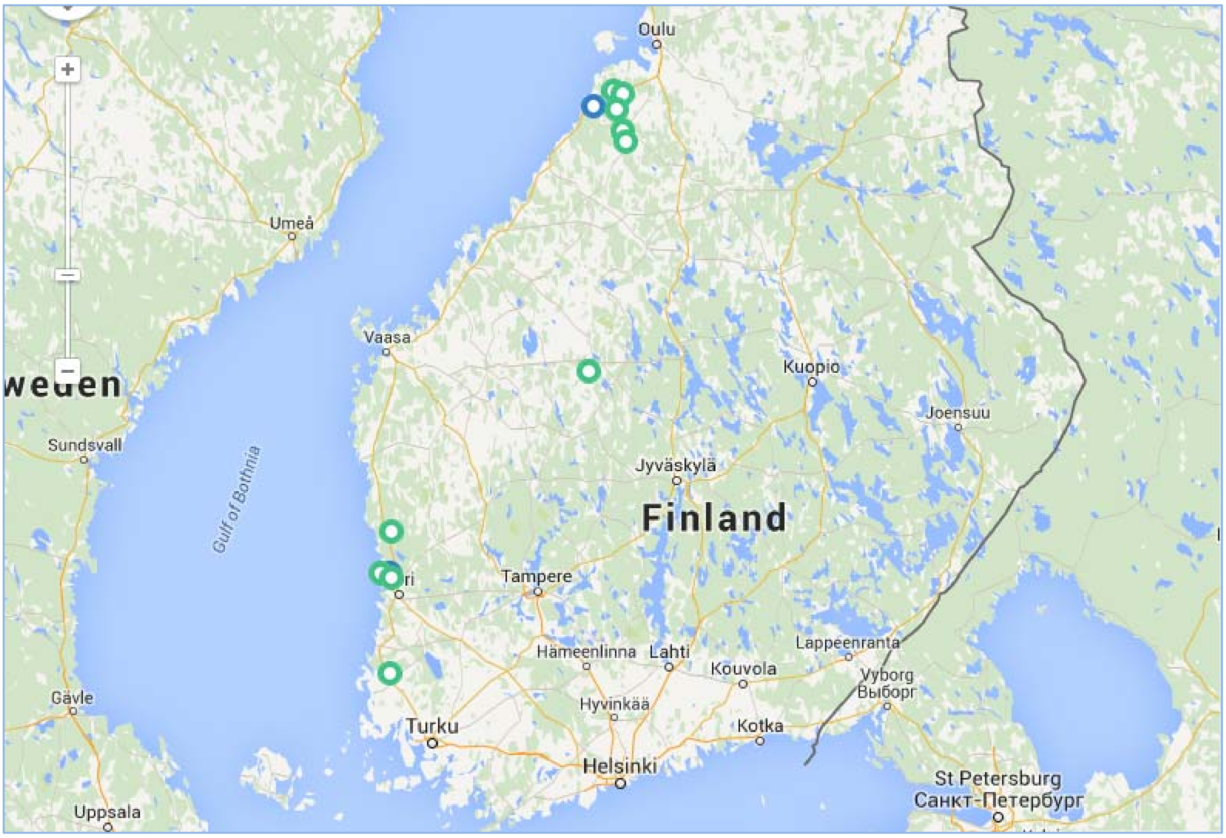

Figure 5.12: Project for wind turbines of Hyötytuuli. The shareholdes of the company are major Finnish City Energy Companies, including Turku. As a matter of simple logic, the wind turbines are situated where the wind blowes, at the western coast of Finland, hence at distance of the shareholders. Other sources of renewable energy production, e.g. solar panels are dependent on proximity with the city, cif. Figure 12. (Source: http://hyotytuuli.fi/en/hyotytuuli/)

5.5.6 Biogas from waste

One of the public services run by the cities is the handling of waste. Therefore, cities are in charge of using waste for different relevant purposes, e.g. incineration and biogas production. Eskilstuna Environment and Energy has set up a production of biogas from waste. The production takes place at the central waste water cleaning plant. In the water treatment process, biogas has been a bi-product since the 1960s. Formerly, biogas it was used for electricity production. Today, it is used as fuel for busses and municipal vehicles, not least because of the branding value. The process is shown in Figure 5.13.

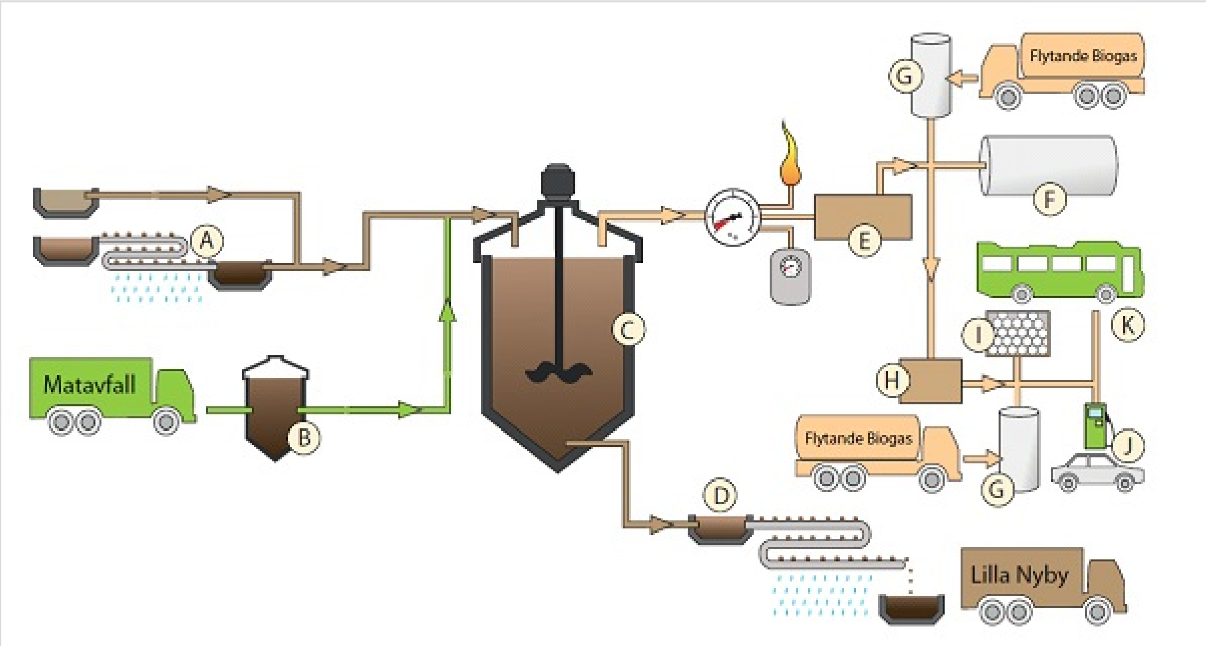

Figure 5.13: Biogas production in Eskilstuna.

A: Sludge from wastewater, B: Waste from food, C: Rot chamber, D: Drainage of remaining sludge, E: Purification of Gas i.e. upgrading from 65 % to 97% methane, F: Tank for storage of biogas, G: Imported liquid methane (for back-up), H: High pressure compressor (300 bar), I: Storage in gas cylinders, J: Public gas station, K: Gas station for busses.

5.5.7 Waste incineration

Waste incineration is one of the energy sources for CHP plants. Usually waste incineration is organised in huge CHP plants run by private companies or by a cooperation of municipalities. However, if not available locally, waste may be exported. This is what city of Turku does. An average of 8 hauls per day is shipped to Estonia every day, to be incinerated at Eesti Energia's new incineration plant from 2013. In 2010 Turku's own incineration plant was laid down, and waste exported to Sweden and since 2013 to Estonia. According to the operations manager at the Turku region waste management company, Patrik Jalonen, emissions from the transport of waste are notably lower than emissions from its treatment. Top priority on municipal waste is to reduce the amount of waste produced and to encourage its re-use. Recycling is the third option and incineration only the fourth. A tender for recycling resulted however, only in bids for in the fourth prioritised category. No tenders for recycling were received. Eesti Energia charges Turku 25 – 40 Euro per tonne of waste (Lehtinen et al., 2014).

5.5.8 Potential energy production: Micro CHP and 'Surface energy'

Besides the above mentioned examples of established energy productions, we shall briefly comment upon a few potential energy productions in the pipeline.

Micro CHP (hydro power cells)

As a tool for storaging power e.g. produced produced by wind turbines, hydro power cells may offer a share. In the village of Vestenskov, Denmark, 32 households were provided with micro heat and power units as part of an international reseach and development project, KEEPEMALIVE testing low temperature fuel cells for stationary power generation and combined heat power production. The Danish pilot project was organised jointly between the Municipality of Lolland, the regional energy company, Seas-NVE, and IRD fuel cells A/S, in cooperation with the Danish parliament, the national power distributor Energinet and the national program for development and demonstration of energy technology, EUDP. The operational phase in Vestensskov is finished and the results are now being evaluated. From the consumer point of view it was a success. The bottleneck and key challenges for a competitive production is to further develop the durability and the price of the power cells Grahl-Madsen (2013).

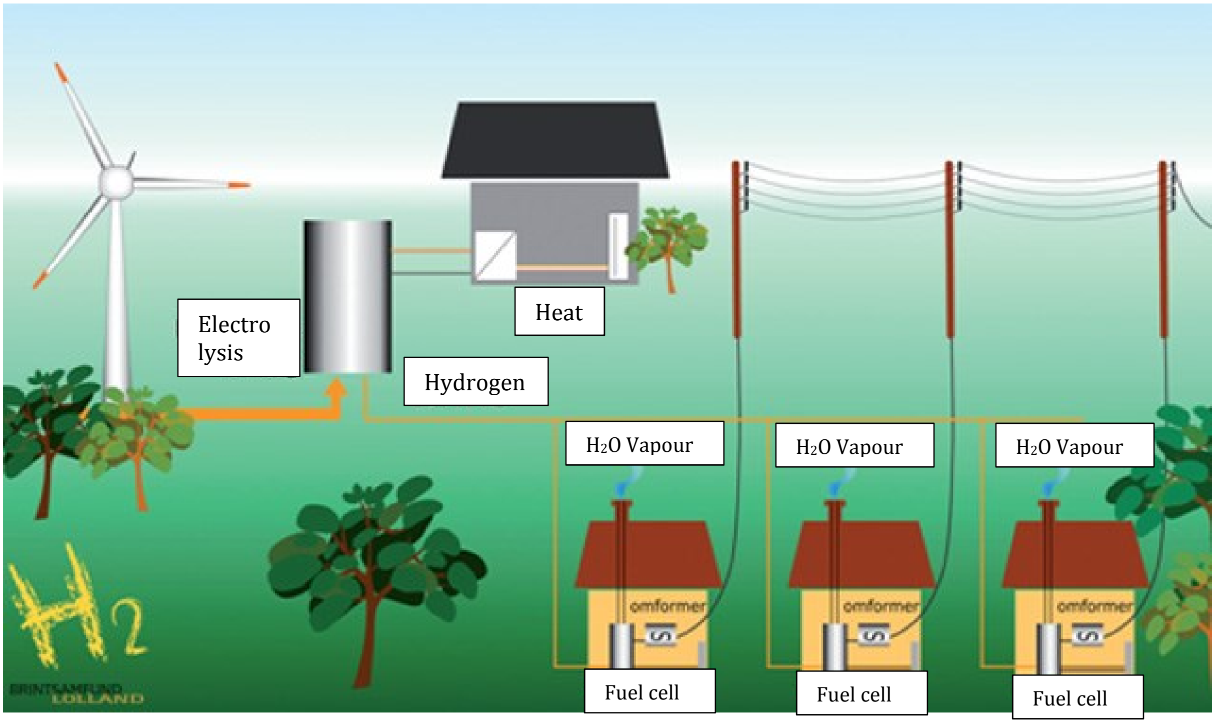

Figure 5.14: Hydro energy and fuels cells in mircro CHP

Diagram of hydrobased micro CHP system. Power from windturbines is used for electrolytic separating hydrogen from oxygen in water. The hydrogen is transmitted by a local hydrogen grid to fuel cells in houses of the customers. The fuel cells produce electricity, heat and H_2O vapour. Excessive power and heat from the households is transmitted to the powergrid heat grid, respectiviely. Source: Grahl-Madsen (2013)

'Surface Energy' (solar cells and infrastructure)

Currently, solar energy is harvested in power cells and heat panels. The solar panels accumulate heat in water which in turn needs circulation in local systems. Solar cells, on other hand, are not restricted by proximity claims. However, as with solar panels they need surfaces. If the surface is primarily provided for energy production (e.g. like the above mentioned solar panel based district heating plant in Vojens, (figure 5.11), the solar energy will consume land. Therefore, secondary locations, notably roofs on buildings, are primarily focused on. Another kind of surface, is roads and bicycle lanes. In the Netherlands, a consortium of research institutions, industry and government is carrying out pilot projects in order to develop mature products feasible for integration in the public infrastructure.

Figure 5.15: Solar cells on bicycle lanes

Bicycle lanes provide surfaces suitable for solar cells. Acronymed 'Solaroad' a consortium of Dutch industry, research institutions and the government has started full-scale developing pilot projects in order to mature the technique. In the first place, the technique is feasible for road lightning. If further developed, power may be transmitted to the general power grid. Source: http://www.solaroad.nl

5.6 National framework - local action

Local energy production is closely related with the national regulatory frameworks. Investments in energy efficiency by individual house owners, private companies and municipal institutions, are influenced by the national climate agenda. However, firsts and foremost, local investments are not taking place until the market makes them profitable or economic incentives are made available by the national government. Each in their own way, the six case studies illuminate the situation.

5.6.1 Jyväskylä

The case study on Jyväskylä notice that "Jyväskylä has, guided by national policy, adopted a strategy in which it deals with potential energy security issues by supplying a large proportion of demand locally, i.e. by making connection to district heating almost obligatory and combining heat and electricity production" (Read & Hietaranta, 2015). Also, Jyväskylä has made a resource wisdom road map (just as Turku) towards 2050, aiming at carbon neutrality in transport and energy production, zero landfill and that residents adjust their lifestyles to fit the 'One Planet Living' approach.

5.6.2 Eskilstuna

The incentives to invest in renewable electricity in Sweden are rather intense. Thus, in 2000, the municipal Eskilstuna Energy & Environment enterprise was paid large national subsidies to support construction of the combined heat and electricity plant in 2000. National subsidies corresponded to approximately 25% of the investments needed for the transformation of the Eskilstuna district heating plant. Thus, the municipal company Eskilstuna Energy & Environment (EEM) received a subsidy of 120 million SEK from the Government as part of the 450 million SEK in total conversion costs.

In addition, the green power certification system has generated an income of 35–70 million SEK per year for the company. If Eskilstuna builds the new plant in Kjula, the enterprise will be rewarded by yearly certificates in 15 years.

The national certification system was launched in 2003. It conveys a flow of financial means from consumers to producers of renewable electricity. Producers of renewable electricity are rewarded with certificates that consumers of electricity are compelled to purchase. The consumers are the daily consumers as represented by energy distributing companies, as well as large, e.g. industrial, single electricity consumers and consumers buying electricity from the Nordic energy grid. Every year, these consumers are assigned an obligatory quota of certificates for purchasing electricity from the renewable energy producers. The end-purchasers of the certificates are the daily consumers and the customers of the industrial goods.

The national subsidies are not equally suitable for all kinds of renewables. Thus, EEM has invested in solar cells, hydro power and wind turbines, but only in minor shares.

Besides the economic incentives, national climate and energy policy includes promotional activities such as inviting municipalities in sustainable activities. One such example is the national corporation program for sustainable municipalities ("Uthållig kommun"). About 35 municipalities take part, including Eskilstuna. The national energy au-

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thority conveys knowledge, resources for cooperation and assistance for formation of network. Especially, ambitious municipalities are addressed, large as well as small, in order to develop and inform about advanced pilot projects.

National incentives are not just oriented to municipalities. Also, national subsidies encourage private homeowners to invest e.g. in solar cells, currently with subsidies of up to 35% of the purchase and installation costs.

National economic incentives and legal regulation are important drivers of energy and climate policies. Added to these 'hard' measures are 'soft' measures are a number of initiatives aimed at influencing public opinion, institutional and private companies. In Eskilstuna, the municipality distinguish between decisions carried out within the institutional framework of the municipal concern – and activities aiming at influencing citizens, NGO, institutions and private companies outside the concern. In the terminology of Eskilstuna, the first kind of initiatives is carried as part of a municipal 'plan', whereas the second kind of initiatives is part of a municipal 'strategy'.

The interplay between national frameworks and municipal execution of climate measures seems so closely connected that it is difficult to characterize the municipality as simply an executor of national policies. To a wide extent, initiatives are developed locally inspired by the generally increasing concern about the climate (Groth, Große, & Fertner, 2015).

5.6.3 Tartu

The framework for the local energy production in Tartu is set by the Estonian national energy policy (Große, Groth, Fertner, Tamm, & Alev, 2015). Besides a general concern about climate issues, the Estonian energy policy is aiming at pressing political issues such as reducing dependency on imported resources and ensuring security of energy supply. A more decentralised regional energy production is taken as a means of improving the overall energy security as well as a better exploitation of local energy resources (wind, solar, biomass, earth heat). Furthermore, integrated energy-production solutions, e.g. combined heat-power-production, shall be further developed to increase energy efficiency.

The major company for energy supply in Estonia is Fortum Eesti AS, part of the Finnish Fortum Group, operating in three cities: the administrative centre in Tallinn and with two CHP plants in each of the cities Pärnu and Tartu. In the 1970s every house in the city centre had its own oil boiler. At the same time the district heating system in Tartu was established in the 1970s. In the 1990s individual gas stations were the favoured energy supply of private households; but as the district heating network was already developed, the city intervened on behalf of the running energy company because it would have become too expensive to keep the network. Currently about 90 % of the apartment houses are connected to district heating; but less than 5 % of the single-family-houses[5] are connected.

[5] The share of the single-family-houses (ca. 7.000) is about 20 % of the total housing stock in Tartu (City of Tartu).

If available, residents have the option of choosing gas rather than district heating, since gas is available in most areas as energy source for cooking. However, in several single family housing areas, neither gas nor district heating is available; in these areas electricity is used for cooking and air-to-air heat pumps and wood furnaces for heating. In appointed district heating zones it's compulsory to connect, unless the energy demand of a house is less than 40 kW/m^2/yr or is supplied in an environmentally cleaner way of heating (e.g. ground heating, solar panels). Though, connecting houses to district heating is always negotiated.

The former Master Plan (1999) included an energy development plan for Tartu city (district heating, electricity) and assigned district heating areas. This was prior to the implementation of the national District Heating Act in 2003 which enables municipalities to establish district heating zones which make connection to district heating compulsory. The current Master Plan (2006) includes further areas in the district heating system. In order to include these new areas the city had to establish stricter regulations in district heating zones, since the energy companies refused otherwise to expand the network due to its high costs.

The Fortum CHP is driven by the heat demand. The electricity is, thus, a residual and sold to the national grid system. The national grid system is connected with Russia, Finland, Lithuania, Latvia and Sweden. The lion's share of Estonian power is produced on oil shale in Narva.

5.6.4 Stoke-on-Trent

In the UK policies like the energy, environment and climate policies are relying on local initiatives. This was emphasised by the UK Government White Paper 2006: Strong and prosperous communities. Also Fudge et al. (2012), notice that the focus of policy making in the UK ”lies on the *leading role of local authorities* in energy conservation, generation and efficiency” (emphasis added). Thus, ’placed based’ – i.e. locally embedded – initiatives was given a prime position in the Low Carbon Transition Plan, launched in 2009 by the Department of Energy & Climate Change. The UK energy policy approaches the local *household* as well as local *enterprises* and local *authorities*.

As an example, the Green Deal program set up the framework for the assessment of the energy performance in households followed by suggestions for technical and economic feasible improvements. Repayments of the work done according to the Green Deal programme are added to the electricity bill. Thereby investments in energy efficiency are directly compensated by savings in electrify production. Most initiatives are about energy savings in the households, but also energy production by e.g. solar cells and panels are eligible. (Rocco, 2015)

Local authorities are asked to produce “positive strategies” in order to promote energy from renewable and low carbon sources as well as supporting community-led initiatives for renewable and low carbon energy. Local authorities should also identify opportunities where development can draw its energy supply from decentralised, renewable or low carbon energy supply systems and for co-locating potential heat customers and suppliers.

The UK energy policy presupposes that local authorities and households are capable of handling projects. It has, however, been observed that the Green Deal program is almost impossible to fit in the needs of most deprived households. It is, thus, much less attractive for low-income households in privately rented homes, since they are unwilling to contract long-term debts that have an impact on their monthly income. Also, fragile households (the elderly, the very poor and the illiterate) are much less inclined to seek the Green Deal, because it is a difficult programme to understand, and their housing arrangements might be uncertain or short-termed.

The local authority, Stoke-on-Trent Council, has empowered its capacity by joining a so-called Local Enterprise Partnership (LEP) with the Staffordshire County Council. LEPs are supported by the government, but formed at voluntary basis by local authorities and business. They have been set up since 2011 partly to substitute tasks that were taken care of by the regional development agencies, abolished in 2012. The Stoke-on-Trent & Trafford shire LEP has been a stepping stone for local energy policies in Stoke-on-Trent. Thus, in 2014 the network won a bid for energy efficiency funds from the central government with an application entitled 'Powerhouse Central Project'.

The project aims to boost energy production and training in the North Staffordshire area. It relies on funds of £113 million over the next 10 years, provided jointly by:

£31.0 million from central Government,
£33.0 million from the North Staffordshire councils,
£43.8 million from private sector partners and
£5.6 million from the European Union.

Most remarkably, the project is introducing England's first district heating plant, based upon fossils free energy sources. Thus, the system is going to be fed by deep geothermal energy, extracted from naturally reservoirs of warm water situated 2 kilometres below the natural terrain.
The benefits of the project include the production up to 45GWh of heat energy annually, lowering heating costs for businesses by up to 10%, saving approximately 10,000 tonnes of carbon dioxide annually and creating or securing a number of jobs. As a consequence of the new technologies in the project, new forms of urbanisation and new forms of public-private partnerships are envisaged.

5.6.5 Santiago de Compostela

In Spain, European Union's energy policies have been a key driving force in the production of national policy on energy efficiency Spain. This includes the 20-20-20 objectives adopted by the European Union.

The basic pillars of Spain's energy policy are: promotion of renewable energy, diversification of energy sources and energy efficiency. From these three policy strands, the development of renewable energies has high priority. Thus, in 2012 more than 27 percent of Spain's power supply came from renewable sources, excluding big hydroelectric generators, compared with around 13 percent in 2007 — one of the highest shares in the European Union. However, the highly subsidised renewable energy sector has been the most affected from a major restructuring of the energy sector in 2013, designed to tackle the huge tariff deficit in Spain, the difference between the real cost of electricity generation and what is paid by consumers (Fernandez Maldonado, 2015).

5.7 Local energy production and urban planning

Local energy production is developing from the broadcast of energy from a few local or regional producers to a much more complex situation characterised at least by three trends:

- Energy production techniques are mushrooming due to a diversification of techniques, resources and scales. However, diversification is also often developed within the specific local context, giving cities a key role.
- Apart from energy production tied to resource availablilty (e.g. wind and hydro) most energy production is becoming decentralised, whereas regulatory frameworks and policies as well as the development of new techniques are becoming more centralised in the hands of national governments, international governmental cooperations and national research institutions and energy companies. These two trends, decentralisation of production and centralisation of regulation, are part of the same overall trend towards a 'networked energy production', crowned in a few years by smart grids, or the 'energy internet'. Still, municipalities need to set their agendas within these systems and take active roles and responsibilities for their territories.
- Generally, downsizing fossil fuels from energy production causes a drive towards electricity based systems. In this system, energy storage is the bottleneck. Two kinds of storage solutions are being developed: technical and relational. Technical solutions are usually on the site of the producer, where as the relational storage is established by connecting energy producers.

Different impacts on the city and urban planning are caused by these trends and techniques.

Site dimension and location
New techniques require sites tailored for the technique. The Vojens solar panel based district heating system is a notable example. As water based system, the site was provided in the city, in scale dimensioned for the 57 000 m2 panels, the reservoir and the plant. In several cases old energy plants are moved from central location in the city to more peripheral location in order to give room for extension e.g. when DH is transformed into DCH.

Traffic generation and logistics
As with the example of relocation of Eskilstuna CHP from the central part of the city to the logistic area 10 km east to the city was promoted by a wish for reducing the daily heavy lorry transport of wood chips in the center of Eskilstuna as well as improving the logistics of regional fuel transport to the plant.

Resource availability
The availability of resources causes diverse restrictions on the location of grids and plants. In Turku, presence of peat quaries in the region is an asset for the Turku CHP.

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Even closer connected are local DH grids and industries delivering excess heat from the production, as in the case of cooperation between the municipality of Frederikssund and the Haldor Topsøe industry.

Loal DH grid tissues
Since the very beginning of distric heating it has been common that investments in the DH plant and grid were desisively depending upon dense grid facilitating dense housing areas developing stepvise in socalled energy districts. Still, density is preferable to the effectivenss of the distric heating system. However, this priority has become second ranking to liberalisation of the energy market and the priorities given individually established sustainable energy solusions. This is the case in Eskilstuna and Turku as well.

Grid districts and clusters
A special challenge to the common energy systems is provided by energy savings. Thus, district heating is only feasible if a certain need for heat is needed from each house hold. The development of zero energy houses has caused a reevaluation of district heating. In the case of Vinge, houses were not planned as zero energy houses, rather just low energy consumers. As an alternative to district heating small clusters of water based heatpumps was chosen for the urban development.

Public works
The idea of reusing waste has caused a turn around for the municipal public works, some of wich are owned by the municipality, whereas others are owned jointly by municiapl cooperations. Some kinds of reuse are bound to the site of the public work. This is the situation, when – as in Turku – heat is extracted from waste water by heat pumps. Solid waste, on the other hand is usually transported to huge incinerators in the region or even abroad.

Urban surfaces – road and roof
Urban environments are characterised by artificial surfaces suitable for multipurse use. Roofs and even facades on buildings are used for solar panels. Other optional surfaces are roads and bicycle lanes, as revealed by the Solaroad initiative in the Netherlands.

City and village – questions on scale
The fact that we live in scattered as well as dense built up areas, calls for energy solutions suited for both. As for example, the above mentioned Heat Road Map Europe 2050 recommends a combination of district heating plants (CHP) in the cities and heat pumps in the scattered built-up rural areas and villages. Along with the heat pumps an alternative may develop, if the micro heat and power units tested in the village of 'Vesten skov' by the KEEPEMALIVE project succeeds. These micro units are especially suited for small settlement rather than large cities.

All in all, the interrelations between urban form and energy production are multifaceted and developing along with new techniques and the introduction of smart grid monitoring. We tried to set up a more generally a number of parameters to consider: the site, the traffic generation, logistics and avilablity of resouorces, the grid and heatpump clusters, public work dependencies, urban roofs and roads and the scale of village and city. All these parameters are relevant and should be considered jointly with the urban paramters of energy consumption.

6 Conclusions and perspectives (Christian Fertner, Evert Meijers)

This section summarizes the main measures, policies and tools reviewed in the previous chapters. We end with some perspectives for the final task in PLEEC's Work Package 4, Deliverable 4.4, which will focus on the six PLEEC case cities.

6.1 A summary of measures, policies and tools

The following list outlines 29 potential measures and policies of spatial planning which can influence the energy profile of a city. The list is structured by the four core themes of this report (buildings, transport, industry, energy generation) and is based on the review done for this report as well as comments by city partners (see Deliverable 4.4, Fertner et al. (2015) for further details).

Table 6.1 Measures and policies of spatial planning to influence urban energy

Sector	Goal	Measure, policy, tool, strategy …
Buildings and the built environment	**A. Optimize energy distribution on district level**	**A1. Incorporate energy efficiency considerations into general strategic** spatial development plan(s), probably considering the city-regional scale (e.g. the project 'Heat Road Map Europe 2050' recommends the combination of district heating in dense urban areas and heat pumps in scattered built up areas.)
		A2. Energy plan for the housing estate (The planning of new housing estates should be accompanied by an energy plan according to which decisions on energy supply (e.g. DH, HP, SP, SC) and energy efficiency of the buildings (e.g. insulation) are settled.)
		A3. Promote apartment buildings and dense housing, limited detached housing (An otherwise identical household consumes 54% less heating energy in an apartment than in a single-family home, tough the gap is narrowing due to new building regulations.)
		A4. Densify existing built-up areas (can reduce infrastructure costs per person)
		A5. Build more compact urban forms: less wide streets, less distance between buildings. (can reduce infrastructure costs per person)
Buildings and built env.	**B. Climate-oriented urban design**	**B1. Translate general measures** in such a way that the local **urban and climate-specific context** are utilised to the max. (Climate-conscious development: adapt general strategies to specific climatic circumstances.)
		B2. Optimise solar access / shading (trees, streets and building orientation) (What is optimal depends on the latitude and climate. There are some rules of thumb, e.g. on housing orientation and tree planting, however, often compromises with other urban design considerations have to be found – What do you prioritize?)
		B3. Optimise wind ventilation / wind blocking (trees and buildings) (Again this depends on the climate, but also on the surrounding topography. Height and density of buildings can affects possibilities for wind ventilation or protection from cold winds. Particularly useful in warmer climates, but less in colder climates, where this may lead to a blocking of solar access. In colder climates, planting trees to the north, or to block winds, can be beneficial as well.)

Table 6.1 Measures and policies of spatial planning to influence urban energy (cont.)

Sector	Goal	Measure, policy, tool, strategy …
Transportation	**C. Reduce travel needs**	**C1. Promote larger settlements** to provide opportunities for self-containment and a good mix of uses. (Larger urban areas provide more opportunities to reduce the need to travel, and to use energy-efficient transport modes. Expansion of larger urban areas is generally preferable to development in smaller towns or dispersing development across a number of smaller settlements.)
		C2. New development should ideally be located **within or immediately adjacent** to larger towns and cities.
		C3. Foster mixed use development. Key local (neighbourhood) facilities and services should be located within walking distance of homes in a neighbourhood. (This not only reduces travel distances (and hence, encourages walking and cycling), but also provides support for shops and services to remain economically viable.)
		C4. Relocate transport intensive industries or power plants (e.g. power plants using biomass to decrease the energy consumption in transport, in Eskilstuna it was estimated that 57% of lorry-rides to bring biomass inputs would be replaced by rail).
	D. Promote 'green' transport	**D1. Locate major new urban developments** (employment, leisure, retail, housing) near public transport nodes and/or close to existing centres (Transit oriented development)
		D2. Locate key services and facilities that serve the entire city or region (shopping centres, hospitals, libraries, educational institutions etc.) within the urban fabric and make sure they are very well accessible by public transport.
		D3. Develop intermodal transport nodes in combination with urban development
		D4. Increase density of development, particularly in areas adjacent to major public transport nodes (Rule of thumb: 10-minute walk, 800 meter radius; this should be consistent with local norms, accommodation needs and liveability objectives.)
		D5. Develop key public transport networks in urban areas
		D6. Develop walking and cycling infrastructure (pavements, shortcuts, separate cycling lanes, parking facilities for bikes).
		D7. Increase the 'permeability' of the network of streets to encourage walking, cycling and public transport use. (Also pay attention to social safety.)
		D8. Avoid development locations that promote long-distance journeys **by car**.
		D9. Imposit maximum parking standards (parking management)

Table 6.1 Measures and policies of spatial planning to influence urban energy (cont.)

Sector	Goal	Measure, policy, tool, strategy …
Industrial	**E. Enable industrial symbiosis by spatial clustering of industrial activities**	**E1. Clustering in space of industrial activities** with complementary energy and waste material outputs and inputs to achieve industrial symbiosis. (Very substantial benefits, not just in terms of energy saving, but for instance also in terms of CO2 reduction. Case studies suggest that fuel efficiency doubles.)
	F. Improve opportunities for co-generation and linkages to district energy systems	**F1. Spatial clustering of industries** to improve opportunities for co-generation of energy and/or support district heating systems (Scale advantages in energy generation, and district heating systems are more feasible in case there is a big industrial consumer present)
		F2. Encouraging heavy energy consuming industries to introduce **combined heat and power** and/or to **combine with local district heating/cooling**
Energy generation	**G. Optimise energy distribution systems**	**G1. Implement district energy systems** to profit from combined heat and power production (CHP). (Local (district) heating systems help utilize heat production from waste incineration and industrial excess heat production, as well as integration of geothermal/wind/biogas/biomass production. In Turku, the CHP plant cuts fuel consumption by one-third. Energy costs for firms in Stoke are expected to decrease by 10%.)
	H. Designate areas for renewable energy production	**H1. Designate areas for large-scale production** sites of hydro/wind/solar/geothermal/ biomass/ biogas energy generation.
		H2. Introduce heat pumps in public works whenever excess heating is available (e.g. waste-water) combined with district cooling when relevant.
	I. Enable small-scale (households) renewable energy generation	**I1. Implement planning guidelines to optimise solar access** of houses to foster households' use of solar panels. (See measures B)
		I2. Remove institutional and legal local barriers for household-scale production of energy (heat pumps, solar).

The list is a step stone towards Deliverable 4.4. However, when discussing the measures for each city, it is important to consider the local context and possibilities as well as interdependencies and synergies between the measures. Also the wider picture of a meausre's impact has to be taken into accoung, in particular potential rebound effects in direct and indirect energy use.

6.2 Interrelations and interdependencies in urban energy planning

The list provided in the previous section can be a helpful tool to get a first overview of potential measures a city can commence to improve its energy profile. However, which actual impact a measure has in the wider urban measures are the best and how can they be implemented in practice is a different question. While we will work on the latter in a following report (Deliverable 4.4), the questions of the general and wider contribution of a particular measure to a city's development has also some general implications which we would like to mention here. This is especially important as cities usually have only limited options to commence measures (because of constrained resources), which makes it necessary to choose those measures with the biggest benefits – and the least drawbacks. Synergies and spilovers are key concepts here, but also life-cycle analysis, cradle-to-cradle concepts as well as feedbacks, rebounds and even backfire effects[6].

> *"Part of the challenge appears to lie in the fact that innovations that alleviate pressures in one area can cause feedbacks that increase pressures elsewhere. Efficiency gains can reduce production costs, effectively increasing consumer spending power and thereby enabling increased consumption (the rebound effect). In the transport sector, for example, increasing fuel efficiency has had limited impact on overall fuel use because it has resulted in increased driving. Similar trends have been seen in many other areas, including household appliances and space heating."* (EEA, 2015)

In the following some examples of such effects are summarized.

Energy efficient buildings offset by increasing comfort and housing area

In chapter 2 we can read about the improving efficiency in buildings, especially related to space heating, in more or less all European countries since 1990. However, while efficiency increased, the total energy use in households did not change significantly in the EU27 in the last 20 years. Population was stable in that period, but in parallel to use energy more efficiently, the energy used for appliances increased as well as the size of houses. Especially the latter is relevant from an urban planning point of view.

So the decrease in energy consumption per m^2 is offset to quite a substantial extent by the increase in volume of houses. In just 20 years the surface of houses grew by almost 30% while population only increase by 7 % (Fertner, 2012). As Figure 6.1 shows, the consumption per dwelling for space heating decreased less than the consumption per m^2. The total energy consumption of houses remained fairly constant over time. This is probably a rebound effect, where cheaper housing (calculated per m2) made bigger houses more affordable.

[6] These effects are also known as Jevon Paradox, read more on http://www.inscc.utah.edu/~tgarrett/Economics/Jevons_Paradox.html and (Garrett, 2012)

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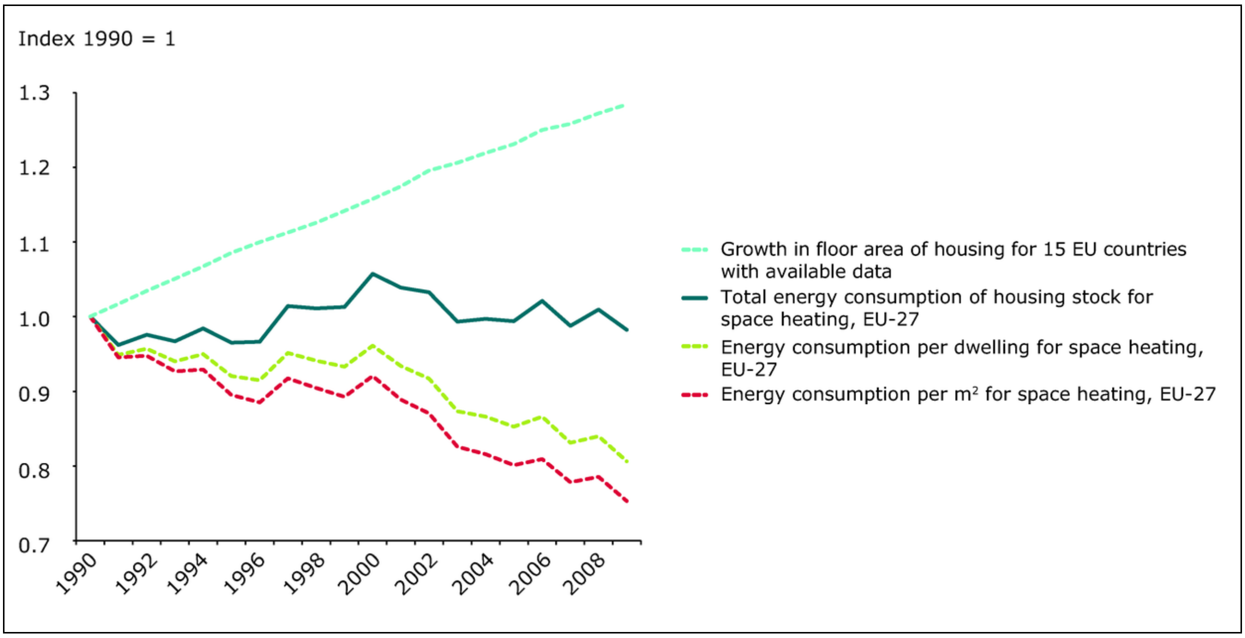

Figure 6.1. Trends in heating energy consumption and energy efficiency.
(EEA, 2010)

Fuel efficiency in private cars offset by increasing comfort and housing area

In the transport sector similar rebound effects can be observed. Although fuel efficiency and emission characteristics of cars improved in recent decades, the growh in car ownership and in distance driven offset these improvements. When cars get more efficient and more comfortable and infrastructure improves, we tend to drive further. This is also one of the reasons for the emergence of functional urban regions as we have them in Europe today, where not the physical city is the main centre for activity, but the wider region, with residences, work places and places for recreation are spread out. The trends in Figure 6.2 also illustrate that technical solutions not always deliver expected reductions in environmental pressures (EEA, 2015).

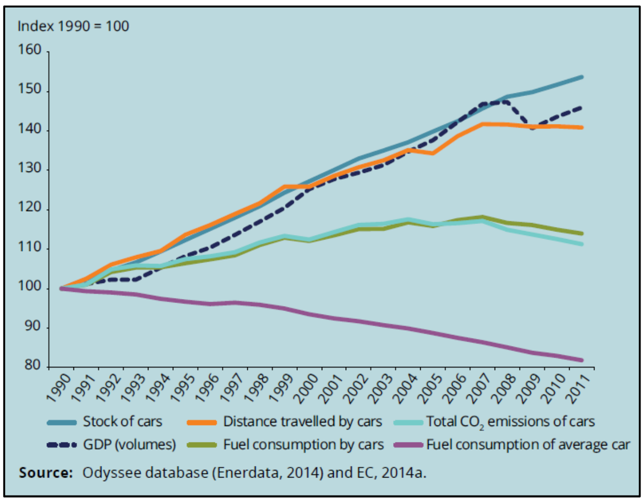

Figure 6.2. Fuel efficiency and fuel consumption in private cars, 1990-2011
(EEA, 2015)

Urban planning can slow down rebound effects within the urban planning sphere, but hardly in the general society…

In both cases – and others conntected to industrial and commercial energy consumption as well as efficient energy supply – urban planning can have a considerable say. Making compact urban living more attractive, e.g. by improving public spaces, or reducing driving needs by creating an integrated transport system can have a positive impact on energy used in housing and transport. However, these efficiency gains have to be internalised in the public system, otherwise, the exceeding capacities (e.g. in terms of money or time available for each citizen) will be used elsewhere, probably in connection with an energy use of a similar level.

For example, a study from Finland showed that people living in compact urban settings tend to have a high use of summer houses (Strandell & Hall, 2015). The lack of open space increases the need of people to travel further for recreational purposes. Similar 'compensation effects' have been observed in Sweden. Axelsson (2012) showed that in the bigger cites like Stockholm, the ecological footprint of transport activities is only half than in many other places. However, for other activities as recreation and culture, the average Stockholmer has a much bigger ecological footprint than the average Swede. The impact of direct energy use (e.g. transport) is transferred to indirect energy use by consuming activities and products.

The transfer, or out-sourcing, of direct (on-site) to indirect (imported) energy consumption is also an important issue, especially in cities of the developed world, which are importing a big share of their consumption. Figure 6.3 shows that a city like Tokyo is importing more than double the energy in the form of embodied energy (in goods and services) and in the form of direct energy (fuels, electricity etc.)

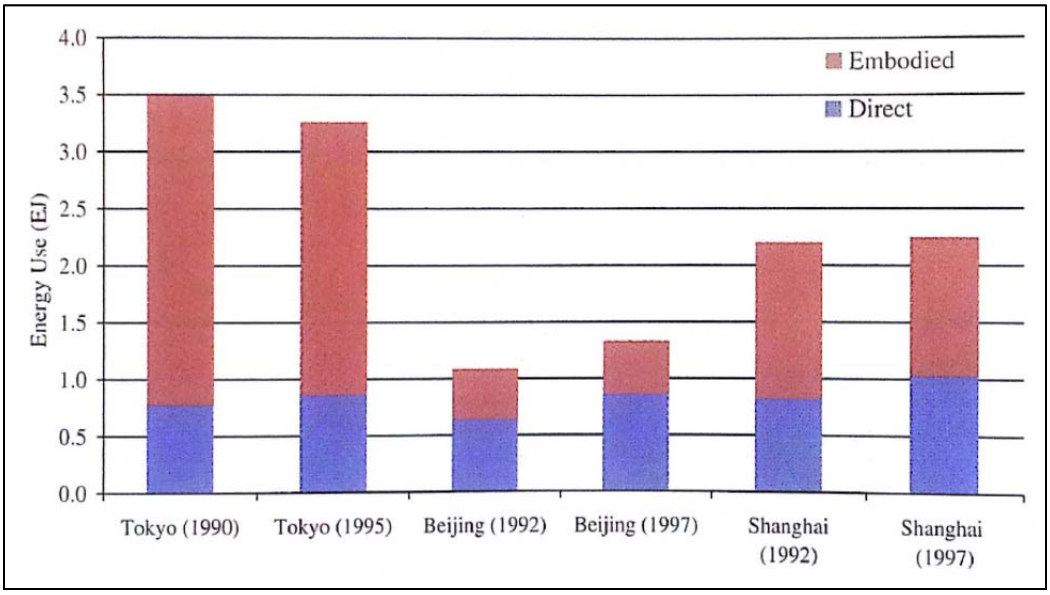

Figure 6.3. Estimates of direct (on-site) versus embodied (via imports of embodied energy in goods and services) energy use of Asian megacities
(Grubler et al., 2012)

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An intergrative perspective is crucial to account for a the full picture of urban energy

The examples above show, that an integrated approach going beyond urban planning, technology or behavioural issues is crucial to account of the full picture of urban energy. This integrative view is also a key issue if the idea of the 'smart city' should be achieved (Kullman, 2014).

6.3 Perspectives for the six case cities

Following this report, work in WP4 will continue in the final Deliverable 4.4. It synthesizes the case study work (Deliverable 4.2) and the thematic work (Deliverable 4.3), by discussing different tools and policies of urban energy planning as listed above for each of the six PLEEC partner cities. The focus lies on the potential application of approaches and tools in each of the cities, setting general ideas on the relation between urban structure and energy use into context. In the report we will also try to discuss the broader picture of energy use in each of the cities (especially potential direct and indirect rebound effects), and what role urban planning has in that.

Besides the system-perspective, an important question will be how transitions actually can be achieved. Cities can more or less have two roles in that (Geels, 2011):

1. Cities (and their governments) as primary actors in national transitions
2. Cities as seedbeds in early phases of national transitions
3. A third role would be that cities play only a limited role, because the topic is more in the sphere of national actors or of individual persons.

However, other authors empahsize the important role of regions to drive transition in climate change issues, especially because local and regional authorities can be front-runners and examples for transition which might be followed by many others (Liargovas & Apostolopoulos, 2014). Recommendations for the six cities will therefore also be influenced by their bigger importance for a general transition towards Energy Smart Cities.

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